THE MEANING OF MUSIC-MAKING FOR COMPUTER SCIENTISTS WITH A SERIOUS MUSIC-MAKING AVOCATION: A PHENOMENOLOGICAL CASE STUDY

A DISSERTATION

submitted by

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Abstract

This study explores the meaning of music-making in the lives of computer scientists who play classical music as their serious avocation. In particular, it investigates their tendencies and capacities to concurrently engage in two such distinct disciplines on a regular basis, by exploring the cognitive, social, and cultural aspects of their concurrent engagement. While current research literature approaches the affinities between mathematicians/scientists and musicians through the presence of mathematical properties of music and through anecdotal evidence involving known persona and their innovations, this study provides a deeper look at the individuals who combine such worlds, in order to better understand how music-making is situated in their lives. Framing this research as a phenomenological case-study, narratives of seven study participants (and two pilot-study participants) are constructed through open-ended interviews, in which the participants relive their experiences of this phenomenon of embracing the two disciplines within a vocation/avocation framework. Using narrative analysis, and to a limited extent sociolinguistic analysis, the essence of this phenomenon is extracted from their narratives in the form of three major themes: participation in musical groups, sharing of cognitive skills across both disciplines, and tendencies to bring the two disciplines together. Given these themes, this study demonstrates the rich lives of these individuals, their high sense of self, ability to give to society, and their occasional ability to reach creative peaks. This study can motivate educators and educational institutions to encourage and support individuals with interdisciplinary interests, and calls for such individuals not to leave behind their artistic passions despite the role pragmatism plays in their career choices. This study can also help educators better understand individuals who are attracted to or engaged in multiple disciplines, and can complement or reaffirm scientific research on cognitive skills used in the disciplines of music-making and computer-science.

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Dedication

This work is dedicated to the memory of my father, Arie Poldi Gottlieb, and to my mother, Yehudit Gottlieb, who continues to inspire me.

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I. Chapter One: Introduction

I am interested in the meaning of music-making in the lives of computer scientists[1] who play classical music as their serious avocation.[2] In particular, I am interested in their tendencies and capacities to concurrently engage in two such distinct disciplines on a regular basis. As such, my research centers on adult computer scientists who play classical music[3] regularly throughout their lives in chamber groups, orchestras, or as soloists.[4] In the following sections, I present the need for the study along with my motivation, my main research questions, my overall theoretical approach to the study, and the organization of this document. For the purpose of upfront clarification of terminology and concepts used throughout the document, this chapter is accompanied with definitions in the form of footnotes.

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[1] Computer scientists combine mathematical/computational skills with engineering and scientific ways of thinking. Like mathematicians they use representations and abstractions to denote concepts; like engineers they design tools, systems, and processes; and like scientists they observe, hypothesize, and test their designed systems. Computer scientists typically work on the theoretical side of computer systems, as opposed to the hardware side. Their foundation is the theoretical study of computing, which is often applied in algorithm development and design, software engineering, information theory, database theory, computational complexity theory, human-computer interaction, computer programming, programming language theory, artificial intelligence, and computer graphics.

[2] The terms "career," "vocation," and "work" are used in this paper interchangeably. The references to "career" are made due to its common use within the context of career-development theories. The term "avocation" refers to serious leisure as coined by Stebbins (2004) to denote activities that are freely chosen but require effort and commitment and for which there are extrinsic as well as intrinsic reasons to participate.

[3] Although I am aware that many of these professionals play various types of music such as jazz, rock, ethnic, etc., my research focuses on classical music.

[4] Organizations like the Boston Piano Amateurs Association (BPAA) provide performance opportunities, master classes, and workshops for adult amateur pianists.

A. The Need and My Motivation for the Study

The common notion that a significant proportion of mathematicians[5] and scientists have affinities for music, while not substantiated quantitatively, has been attributed largely to anecdotal evidence involving known persona and to the mathematical properties of music. With both anecdotal and mathematical-oriented literature focusing mostly on the findings and innovations pursued by these individuals, I find the need to conduct a deeper look at the lives of the individuals who combine such worlds in order to better understand how music-making is situated in their lives. The anecdotal literature typically provides passing descriptive accounts or citations of known scientists or mathematicians who are also musicians. For example, Novak and Barnett (1960) briefly discuss physicist and violinist Einstein (1879-1955) and chemist/doctor and composer Borodin (1833-1887). Root-Bernstein (2001) identifies scientists who build musical instruments and compiles a list of two dozen scientists and mathematicians who are also composers (e.g., mathematicians Ansermet (1883-1969) and Dabby (contemporary); cardiologist Bing (1909-2010) and physicist Thirring (contemporary)). Further passing accounts (e.g., mathematician Nevalinna (1895-1980), mathematician/engineer Xenakis (1922-2001)) are provided by Root-Bernstein, R. and M. (1999) through their analysis of the cognitive skills they believe are commonly shared by artists and scientists.

The mathematical-oriented literature, on the other hand, explores the mathematical properties of music. For example, Fauvel, Flood, and Wilson (2000) describe historical and modern uses of mathematics in acoustics and aesthetics of music (e.g., physician/physicist Helmholtz (1821-

[5] In today's occupational world, the vocation of computer scientist resembles closely the vocation of a mathematician. In addition, as recent as 35 years ago, computer science was often housed within mathematics departments in academia.

1894), in scale formation (e.g., Pythagorean scale[6]), and in composing music (e.g., Schoenberg's (1874-1951) 12-tone system,[7] Xenakis' stochastic[8] music). Graves (1981), who overlaps with some of their coverage, expands on the use of mathematical group theory,[9] and adds the use of electronic/computerized music and of fractals[10] by composers/music-theorists Babbit (1916-2011), Lewin (1933-2003) and Solomon (contemporary), respectively. Rothstein (1995) explores the (conscious or unconscious) presence of mathematics in classical musical compositions, such as those of Bach (1685-1750), Bartok (1881-1945), Beethoven (1770-1827), and Mozart (1756-1791), while Hofstatder (1979) focuses on Bach, and Chang (2007) focuses on Beethoven and Mozart for the purpose of practicing piano performance in a scientific manner.

Although both anecdotal and mathematical literature acknowledges the affinities between these two seemingly different disciplines of music and mathematics, it explores these affinities within a framework that minimizes the voices and experiences of the people who live (or lived) in these two worlds. It also does not give much attention to the meaning music has in the lives of these individuals, and to the significance this meaning may have in contributing to understanding the affinities between music and math-based disciplines. Moreover, it blends

[6] A Pythagorean scale is based on Pythagorean tuning in which the frequency relationships of all intervals are based on the ratio 3:2 (perfect fifth).

[7] The 12-tone system is a method of musical composition, ensuring that all 12 notes of the chromatic scale are given more or less equal importance, whereby the music avoids being in a key.

[8] Xenakis' stochastic music used probability theory to determine the duration, pitch, timbre, and dynamics of the music.

[9] A mathematical group is an algebraic structure consisting of a set of elements and an operation on these elements, such that when the operation is applied, it yields results satisfying some mathematical conditions. For example, the set of integers is a group.

[10] Fractals are self-similar patterns, as they are "the same from near as from far." On a simple level, fractals are generated by taking a basic "seed," structure, or musical motive, and applying an iterative formula to that seed, structure, or musical motive multiple times. Fractals exist in nature, mathematics, music, etc. Fractal music applies fractal geometry for analyzing music and composing music.

mathematicians with scientists, and does not address the more contemporary math-based discipline of computer science.

My primary motivation for conducting a deeper look at the individuals who combine the worlds of computer science and music is combined with my familiarity with numerous musical computer-scientists and my own interdisciplinary experience with these domains. My interdisciplinary life story interweaves academic interest and experience in the disciplines of mathematics, computer science, music, and linguistics. As a student, I obtained degrees in both music and math/computer science. Continuing to pursue these two disciplines concurrently, I worked as a computer scientist for two decades, applying mathematical and abstract computational skills to the design and development of human computer interfaces using spoken language. In the course of this demanding time, I did not let go of playing music, but rather practiced and performed as a pianist with a chamber music group, which I am a member of to date.

Driven by the perspective of the current literature and by my own interdisciplinary experience and interactions, I attempt to capture the voices of people who work as computer scientists who engage in both disciplines. Creswell (1998) implicitly affirms my motivation for this study by suggesting that “the strongest most scholarly rationale for a (case) study, I believe, follows from a documented need in the literature for increased understanding about an issue” (p. 94).

B. Research Questions

In searching for the meaning of music-making for computer scientists who play classical music as their avocation, I attempt to obtain answers to three main research questions:

1. *What are the cognitive, social and cultural inclinations of computer scientists with a music-making avocation?*

2. *How are they capable of concurrently engaging in these two seemingly disparate worlds on a regular basis?*

3. *How is their concurrent engagement informing their thinking and learning paradigms at work?*

In order to obtain answers to these questions, I engaged in open-ended interviews with individuals who experienced this phenomenon of embracing the two worlds of computer science and music-making in a vocation/avocation framework. Through their reflections on their family background, childhood interests, learning experiences and thinking paradigms, and the turning points and reciprocal effects of their concurrent music and work engagements, I reached the essence of that phenomenon and constructed the meaning of music-making for them.

C. Theoretical Foundations of My Research

The significance of music-making in the lives of individuals with a computer-science vocation and a music-making avocation can be appreciated through their cognitive skills as well as through the lens of their vocational/avocational choices, affected by cognitive, social and cultural factors. From a cognitive development perspective, some cognitive skills used in music-making are believed to be related to computational skills and scientific ways of thinking such as pattern recognition, pattern formation, visual thinking, empathy (Root-Bernstein, R. and M., 2001; Rothstein, 1995), and aesthetics (Rothstein, 1995; Wannamaker, 2001). Recently, several correlational studies have also pointed to links between music training and improvements in spatial/visual[11] ability (Hetland, L., 2006b), which is known to be important in

[11] The ability to mentally manipulate and reason about visual images.

engineering and in some mathematical and scientific disciplines. The vocational and avocational choices this special group of people makes when combining these disciplines into a vocation/avocation framework are likely to be affected by these interrelated cognitive skills as well as by cultural factors (e.g., family background), social factors (e.g., life style, economic aspects), and by considerations of internal gratification (Stebbins, 2004).

With cognitive development and vocation/avocation development comprising my main areas of study, I set out to capture the lived experiences of individuals who experienced this phenomenon of parallel engagement in such disparate fields. Framing my research in a phenomenological case study (Moustakas, 1994; Husserl, 1999), I co-constructed with seven study participants (and two pilot participants) their narratives in which they relive their experiences of this phenomenon. Using narrative analysis tools (Mishler, 2004; Gee, 1999; Labov, 1997; Linde, 1993), and to some extent, sociolinguistic analysis[12] (Ribeiro, 2006; Davies, B. and Harre, R., 1999), I extract the essence of this phenomenon from these narratives in the form of common themes shared across these participants, providing a rich textured description for each theme.

D. Organization of the Study

In the following chapter, I discuss the literature that informed my research, organized by area of study. Chapter three, the Methodology chapter, presents my line of thinking in arriving at my methodological approach for the study, including the specific data collection methods, analysis methods, and my observations of the pilot study conducted prior to the actual study. In chapter four, the Data (Stories) chapter, I present the life stories for each of the seven study participants,

[12] Sociolinguistic data analysis is a discourse analysis approach that is applied to the analysis of written and spoken language, and studies language as influenced by social and cultural factors such as age, gender, ethnicity, class, religion, education, race, etc.

created directly from their interview-based narratives. These stories also help familiarize the readers with the study's participants. Chapter five, the Thematic Analysis chapter, is the heart of study. It brings out the main themes and subthemes that emerged from the narratives of the study participants. The final chapter summarizes the results of this study, briefly discusses the presence of additional themes, and presents my conclusions, including limitations of the present study and recommendations for future research.

II. Chapter Two: Literature Review

In this chapter, I explore the literature I used to inform my study. I begin with the literature on the relationship between scientific, mathematical, and artistic disciplines that contributed to the motivation and initiation of this study. I proceed with the literature that underlies the two main areas that informed my understanding of this interdisciplinary study: cognitive studies, including cognitive development and cognitive skills, and career/leisure development. I conclude with a review of the literature that informed my research paradigm for interpreting the narratives of the study participants and for presenting my thematic analysis.

A. Relating Scientific/Mathematical and Musical Disciplines

The relationships between science and the arts, and math and music in particular, go back in history to the ancient Greek times of Pythagoras (c. 580-510 BC) when music was regarded as a science, and have received attention in the interdisciplinary research literature during the past 100 years. Although the discussions in this literature minimize the voices of the individuals who partake in this interdisciplinary field, they report on the use of common, underlying theories in these disciplines by scientists, mathematicians, musicians, and researchers, adding a dimension to the understanding of the meaning computer scientists[13] may assign to their daily parallel engagement in music-making.

Fauvel, Flood, and Wilson (2003), in their collection of articles on the relations between music and mathematics, review the mathematical principles underlying various aspects of music along the acoustic, harmonic, and compositional dimensions, with the individuals who explored these aspects. Along the acoustic dimension, they explore the presence of mathematics in the

[13] As previously mentioned in the introductory chapter, computer science was often housed within mathematics departments in academia as recent as 35 years ago.

regularity of vibrations, interrelations of tones like consonance, dissonance, and scale formation (e.g., mathematical properties of the Pythagorean scale and the later adjustment to the equal-tempered[14] scale). They describe how music harmony of whole-number frequency ratios informed astronomers Kepler's (1571-1630) and Mersenne's (1588-1648) explanations of the ratios of vibrations created by the motions of the planets, the use of Fourier analysis[15] in the fret[16] design of the guitar, and Helmholtz's (1821-1894) contributions in the understanding of the phenomenon of combinational tones, where two tones played together produce additional tones. They proceed with the more sophisticated mathematical aspects of music, such as the presence of geometry (e.g., fractals) and group transformations[17] in musical compositions (e.g., Bach, Beethoven, Bartok, Schoenberg (1874-1951), Xenakis) and the use of such mathematical structures for composing music.

A more philosophical account on the link between mathematical and musical ideas is explored by Rothstein (1995) in his book *Emblems of Mind: The Inner Life of Music and Mathematics*. In questioning the meaning of mathematics and music, Rothstein reflects on their shared abstractness and beauty. He considers the group transformations discussed in Fauvel et al. (2003) to be the abstraction models that drive the knowledge in both music and mathematics, via the reduction in the number of elements involved, saying that: "…we begin with objects that look dissimilar. We compare, find patterns, analogies with what we already know. We step back

[14] An equal-tempered scale is based on a system of tuning in which the frequency ratio of each interval between two adjacent notes within an octave on a keyboard is the 12th root of two, allowing music to be transposed between keys without changing the relationship between notes.

[15] Fourier analysis is a representation or approximation of functions by sums of simpler trigonometric functions.

[16] The fret is the raised portion on the neck of a stringed instrument.

[17] A group transformation (or mapping) in a particular space is a rearrangement of the elements in that space that can be written by a simple mathematical formula. For example, transposition of a musical key to another key is a transformation within the melodic space.

and create abstractions, laws, systems, using transformations…" (Rothstein, 1994, p. 229). He explores the notion of beauty in math in the context of elegant proofs, which use a minimum of additional assumptions and whose method can be easily generalized to solve similar problems (e.g., Gauss's[18] (1777-1855) theorem on the sum of arithmetic series). This resembles the elegance of many musical compositions (e.g., the classical sonata), which arrange musical ideas around an exposition of a theme, followed by the development of the theme, the recapitulation of the exposition, and a short, concluding coda.

A detailed example of the presence of mathematical group transformations discussed by Fauvel, Flood, and Wilson (2003) and Rothstein (1995) is provided by Chang (2007). He demonstrates how Beethoven, who may not have been aware of such mathematical models while composing, applied group transformations of translation, rotation, mirror, inversion, and the unitary operation in the spaces of pitch, rhythm, and volume, to his famous introductory theme of (G-G-G-**Eb**[19]) in the first movement of his known Fifth Symphony in C Minor, Op. 67.

The presence of the construct of recursion where objects and ideas refer back to themselves is demonstrated in mathematics, music, and the visual arts by Hofstadter (1979), mainly through the commonalities in the thought process of J. S. Bach, logician K. Gödel (1906-1978), and graphic artist M. C. Escher (1898-1972). This construct shows up, for example, in Bach's canons where a sequence of key modulations make the canon sound as if it loops forever (Hofstadter, 1979, pp. 122-123), in Escher's lithograph of two hands drawing each other (pp. 689-690), and in

[18] Gauss recognized that if you take the first and last numbers in the series (1 and 100) and add them you get 101; if you add the second and next to last numbers in the series (2 and 99) you also get 101; and so forth until you arrive at the middle of the series (adding 50 and 51). There were 50 pairs of numbers, meaning that the sum of the series is 101 x 50 = 5050. This method seems beautiful since it avoids the tedious adding of the numbers one by one; it recognizes a pattern and uses that pattern to understand the symmetry of the numbers; it exhibits simplicity in contrast to the size and complexity of the problem proposed (all one needs is to add the first and last numbers); it is general and applies to all series of numbers which differ by a constant amount, like: {4, 7, 10; 13; …301, 304}; and it offers surprise.

[19] Four musical notes of G, G, G, and E flat, with the boldfaced E flat denoting a longer duration.

Gödel's theorems (pp. 449-450), whose proofs hinge upon self-referential mathematical statements (e.g., the system of natural numbers cannot prove the truth of many statements about itself).

Graves' (1981) doctoral dissertation overlaps with some of the mathematical models discussed by Fauvel, Flood, and Wilson (2003), expands on their discussions of mathematical group theory, and complements their publication with articles by musicians and music theorists on electronic/computerized music and use of fractals. Graves also surveys and annotates 75 relevant math-music publications from the period of 1929-1980 with the mathematical background required for their understanding, many requiring high-level math such as number theory, group theory, matrix algebra, and modular arithmetic. Unlike other researchers, he warns not to be carried away with the mathematical applications as compositional devices, as there is no a priori reason to believe that the results will be meaningful, nor for analyzing music, as the underlying mathematics is complicated and sometimes erroneous. Along the same line, he calls for a tighter collaboration between mathematicians and musicians, believing that this collaboration can help reduce errors and simplify notation in music compositions, as well as yield math-music publications comprehensible to mathematically unsophisticated readers.

A variant to Graves' (1981) call for collaboration between mathematicians and musicians is echoed in C. P. Snow's historical call in his book *Two Cultures* (1959), to bridge the communication gap between the sciences and humanities, although motivated mostly by geopolitics and the need to solve the wealth gap caused by industrialization. Snow mourns that breakdown as a combination of practical, intellectual, and creative loss, and suggests the gap can shrink by rethinking our education system, which should not be too specialized.

The above mathematical literature on music demonstrates the ongoing preoccupation of known mathematicians, scientists, and music theorists with the mathematical presence in music, dating as far back as the time of Pythagoras. In the following section, I discuss the literature on cognitive development and cognitive skills that could potentially explain the processes involved in attaining their abilities to do so.

B. Cognitive Studies

The abilities and tendencies of professional computer scientists to keep music-making as their serious avocation can be associated with their cognitive skills. Therefore, cognitive theories that account for the development process of knowing, including the organization, acquisition, perception, and the transfer of knowledge, are central to my studies and inform my research in cognition of musical and scientific knowledge.

1. Theories of Cognitive Development

Cognitive-development models, ranging from native-oriented to neo-Piagetian models differ in their accounts on the emergence and development of cognitive skills and on the treatment of individual differences. As such, these models can inform my understanding of the development of cognitive skills of musical computer-scientists. This section begins with a review of a representative set of stage-based, cognitive-development theories[20] (Piaget and Szeminska, 1941; Werner, 1957; Bruner, 1971) in which each stage represents a qualitatively different and more abstract thinking ability than its former stage. This attainment of abstract thinking within a domain has been discussed in the literature on cognitive-transfer theories (discussed in the Skills

[20] Additional stage-based theories such as Erikson's stages of psychosocial development and Kohlberg's stages of moral development are not discussed in this study, as they focus less on cognitive development and more on the self and personality, and on moral development, respectively.

Transfer section) as an important factor in the potential transfer of cognitive skills across domains, and is thus a valuable concept for my research.

Piaget and Szeminska (1941) developed a stage-based, cognitive-development theory based on their observations of children's interactions with objects in their environment. Their model is based on four age-dependent stages of cognitive development, including sensorimotor (e.g., knowledge from physical actions like seeing), preoperational (e.g., pretend play), concrete operational (e.g., using logic), and formal operational (e.g., using abstract knowledge). Development progresses through the stages with the process of assimilation (using existing knowledge to deal with a new situation) and the complementary and more complex process of accommodation (creating new knowledge when existing knowledge needs to be changed to deal with a new situation).

Werner's (1957) and Bruner's (1971) developmental models are also stage-based, but add specific stage-based transformations that enable the move from simple to more complex modes of knowledge representation. Werner's model, which has a biological/organismic orientation, depicts an orthogenetic[21] (i.e., directional) process of differentiation and integration of knowledge, along with progression/regression where "one has to regress in order to progress" (Werner, 1957, p. 139). Bruner's model, which demonstrates a cultural/social orientation depicts a gradual shift from the enactive representation (action-based and anchored in space/time), which is holistic and undifferentiated, to the iconic (image-based) and then to the symbolic (language-based) representations, which are further removed from space/time and are more analytical.

Vygotsky (1978), whose orientation is more social and cultural than Piaget's and Werner's, believes that students learn through social interactions and culture, rather than by acting on their

[21] Ortho means direction; Genesis means origin of development.

environment. The core of his sociocultural theory is the concepts of the Zone of Proximal Development (ZPD) and scaffolding. ZPD denotes the distance between what children can do by themselves and the next level of learning they can achieve with help. This distance can be reduced or eliminated via scaffolding, when a more knowledgeable agent, like a teacher, can provide temporary scaffolds or supports to facilitate the learner's development. Scaffolding can be progressively withdrawn as the learner develops more sophisticated cognitive systems. The notions of ZPD and scaffolding, like the notion of abstract thinking, play an important role in cognitive-transfer theories, as discussed in the Skills Transfer section.

Unlike the above Piagetian[22] ladder-like developmental models in which cognition progresses as a series of clean and elegant static stages, and individual differences are ignored, Fischer and Bidell's (Fischer and Bidell, 2006) theory, termed dynamic skill theory, reflects the dynamic, constructive, and contextual nature of human development as well as its inherent variability. According to this theory, skills develop dynamically and in multiple directions (not only upward) as strands in a web, continuously integrating and differentiating along their developmental pathway, causing the emergence of new skills that are qualitatively different. As such, this theory can support the possibility that strands corresponding to musical skills (i.e., skills in the source domain) might integrate, at some level along their developmental pathway, with strands in other target domains like computer science and mathematics and contribute to the development of these target skills. The web's vertical space can be thought of as denoting cognitive development along four developmental tiers (e.g., innate reflexes, sensory-motor actions, symbolic reasoning, and abstract reasoning) that are hierarchically structured themselves into more refined levels. Integrative changes of small steps within a tier, as well as steps that

[22] Piaget's (Piaget and Szeminska, 1941), Werner's (1957) and Bruner's (1971) models are considered Piagetian-like models.

yield movement to subsequent tiers, represent qualitative changes within a skill. Its horizontal space can be thought of as denoting cognitive domains (e.g., moral reasoning, reading comprehension, numeracy,[23] music perception).

Gardner's (1993) model of multiple intelligences theory depicts cognitive competencies as less dynamic than Fischer and Bidell's (2006), believing in distinct intelligence modules each having its unique genetic components combined with environmental effects. His theory, which includes intelligences such as bodily-kinesthetic, interpersonal, intrapersonal, linguistic, logical-mathematical, musical, and spatial/visual is thus less capable of explaining the transfer of logical-mathematical skills to music skills or vice versa.

Finally, Karmiloff-Smith (1994) retains some nativist aspects in her theory of progressive modularization of innate dispositions, but is a developmentalist at heart, like Fischer and Bidell (2006). Each domain (e.g., numeracy, literacy, music) begins with its own innate architecture, to which are added representational adjunctions on the basis of involvement from the external environment. As such, she assigns importance to individual differences and acknowledges their existence across multiple dimensions such as typical/atypical development, domain-specific (e.g., verbal ability, spatial/visual ability) versus domain-general (e.g., IQ), and cognitive abilities (e.g., reasoning).

The above literature on cognitive models describes a range of cognitive-development theories that differ with respect to their capacity to account for transfer of cognitive skills, individual differences, and with respect to the significance they assign to nurture versus nature in cognitive development. The following section expands on literature that supports interactions of nature with nurture, rather than nature versus nurture in cognitive development.

[23] The ability to reason and to apply simple numerical concepts.

2. Interaction of Genes and Environment in Cognitive Development

For a long time, scientists have held the naïve conception of genes versus environment in which variation in cognitive development is due to either the individual's genes or the individual's experience, and of genes being deterministic of one's phenotype (organism's observable characteristic). However, a more sophisticated conception of genes with environments has recently been voiced, in which cognitive development is the result of gene-environment interaction, and genes are nondeterministic. Unpacking this more sophisticated conception suggests that environmental factors affect gene expression (Ridley, 2003; Grigorenko, 2007; Ehrlich and Feldman, 2007; Harris, 1998), and that genes affect the environments experienced and sought by individuals (Scarr and McCartney, 1983). This literature on the interaction of genes and environment can help explain the tendencies of computer scientists to be seriously engaged in their parallel activity of music-making as a combination of their inherent abilities with their environments.

Ridley (2003) explains the notion of environmental gene activation, with genetic "thermostats" that control gene activation during development with environmental factors such as education, food, fight, or love. These thermostats form the structures of human brains by engaging the environment in a feedback loop in which experience changes gene expression, which in turn changes the brain, which again changes gene expression, thus having the environment and genes work together.

Grigorenko (2007) claims that the school is a major player in modifying the children's gene expression, as reflected in the manifestation of different genetic predispositions. She agrees that the individual's "genetic script" is both inherited and sensitive to environments, and that phenotype is determined both by one's genes and environment. She encourages educators to change their bias toward over-interpreting the role of genetic factors and to not assign determinism to genes. Genes are typically probabilistic, not deterministic, as she has shown with survival curves of rats that died at very distinct times despite being bred to be genetically identical (Grigorenko, 2008).

Ehrlich and Feldman (2007), whose theory on the role environments play in gene expression draws extensively upon twin studies, explain the gene-environment interaction from a biological computational perspective. They claim that while genes influence human behavior, the human genome does not have remotely enough genes to program all the connections in the brain that control behavior, and thus environmental factors must play a significant role in programming these connections together with the genes. Genes do not determine nor are they responsible for human behaviors, and there is little understanding as to how environments determine them.

Harris (1998) argues that it is not only the parental environment that influences personalities of children but that genetics should be considered too. First, many socialization studies that studied such parental influence failed to control for genetic influences. Second, the relationship between parent and child is a two-way street such that parents may treat children differently because the children are different. Finally, she observes that children identify more with their peers than with their parents, and have an innate capacity to separate their home life from their other lives.

Scarr and McCartney (1983) concur that development is the result of nature and nurture but that genes drive life experiences, pushing and restraining them. Genotypes[24] help determine which environments are actually experienced and what effects they have on the developing person. As such, it is more likely that people with certain kinds of genotypes will select certain

[24] The genetic makeup of a cell, an organism, or an individual.

aspects from their available environments. This connection is probabilistic, diminishes with development, and is decreased through unusual positive or negative interventions (e.g., deprivation, adoption, day care).

The above literature collectively acknowledges that genes and environment interact in affecting cognitive development, but varies with respect to the roles environments and genes play in that interaction. In addition to being affected by genes and environment, cognitive development interacts also with cognitive forces such as motivation and with the experience of flow,[25] discussed in the following section.

3. Cognitive Forces: Motivation and Flow

Underlying human development are two related constructs of the force of motivation that moves us to engage in something, and experience the rewarding quality of this engagement, which is an important factor in participating in that engagement. The literature on motivation and flow can explain some of the reasons musical computer-scientists engage in two such demanding disciplines.

In their study of motivation, Ryan and Deci (2000) present a model for their Self Determination Theory (SDT) which distinguishes between intrinsic motivations[26] (doing something that is inherently interesting) and extrinsic motivations (doing something because it leads to a separable outcome). They also refine the concept of extrinsic motivation to include controlled motivations (in addition to autonomous ones), thus presenting them in a more positive light than previously described. In the context of my study, the SDT model would consider a

[25] The mental state in which a person is fully immersed in what she or he is doing and which is typically experienced when skill intersects with challenge.

[26] Stebbins (2004) lists intrinsic motivation as one of the characteristics of serious leisure such as the music-making activity examined in this study.

child who studies music performance only to accommodate his or her parents' will as having controlled motivation, but as autonomous yet extrinsically motivated, if the child studies music because she or he values it for a chosen career. Along with Vansteenkiste, Simons, Lens, Sheldon, and Deci (2004), agree that while controlled motivations drain energy, autonomous motivation is vitalizing. In addition, emphasis on intrinsic goals is associated with greater health, well-being, performance, and with improved learning skills.

Flow, a construct introduced by Csíkszentmihályi (1990), is a rewarding state one reaches through the setting of challenges when accomplishing tasks that are neither too difficult nor too simple for that person's skills and abilities, along with setting clear goals and receiving immediate feedback. When in the state of flow, one is totally engrossed in the activity at hand, to the point of loss of self-consciousness. Csíkszentmihályi (1990) reiterates that most real life, enjoyable activities are not natural, and that "…they demand an effort that initially one is reluctant to make. But once the interaction starts to provide feedback to the person's skills, it usually begins to be intrinsically rewarding" (p. 68). Such state of flow is achievable, for example, in sports activities, listening to music, making music, and even at work. Timothy Gallwey (1977), who authored the book *The Inner Game of Tennis*, describes a mindset for achieving flow in a tennis game, through playing the *inner game* by stretching one's own abilities, versus the *outer game* which is played against opponents. Stebbins (2010), an expert on serious leisure, asserts that the majority of serious leisurely activities generates flow but warns not to conclude that all do as not all of them have been studied, like liberal arts activities (e.g., reading).

While the cognitive literature discussed so far (i.e., cognitive-development theories, affects of genes and environment on cognitive development, cognitive elements of motivation and flow) is general and applicable to all cognitive skills, the literature discussed in the following two sections pertains specifically to cognitive skills shared by the specific groups of scientists/mathematicians and artists/musicians.

4. Relations between Cognitive Skills of Scientists/Mathematicians and Artists/Musicians

This section discusses the phenomenon of cognitive skills that are similar across domains, and zooms specifically on spatial/visual and aesthetic skills believed to be shared by scientists/mathematicians and artists/musicians.

a. Sharing of Cognitive Skills

The literature in this category zooms in on specific cognitive skills that are believed to be shared by scientists/mathematicians and artists/musicians. The leader of this line of thinking is biologist and physiologist Root-Bernstein who along with his team (Root-Bernstein, Bernstein, and Garnier, 1995) performed mixed qualitative and quantitative research, reexamining data collected from forty male scientists between the years 1958 and 1978, including four Nobel prize winners. These scientists, belonging to various scientific societies such as Nobel laureates, Royal Society, National Academy of Sciences in the USA, Sigma Xi (general representation of scientists), and the U.S. public, were interviewed about their typical modes of thinking (e.g., verbal, abstract, visual, kinesthetic), their childhood and adulthood hobbies, and the circumstances when having significant scientific insights (e.g., while working on problems directly, while working on other problems). The analysis shows that scientific success (measured by number of cited articles and their annual citation frequency) is highly correlated with visual thinking, that musical and visual arts hobbies are highly correlated with visual thinking, and that scientific success is highly correlated with the ability to manage competing vocational and avocation activities. The results also demonstrated significant relations between success as scientists and engagement in arts and crafts avocations, with the Nobel Laureates having the largest average number of arts and crafts avocations among all the other groups. This correlation between scientific success and artistic engagement can be explained by the wider exposure to artistic activities people in the more scientific societies may have, as compared with people in other societies. The results raise questions regarding whether scientists are genetically endowed with such a broad range of unrelated talents, whether they are just energized and driven to explore diverse hobbies, whether their vocations are just manifestations of their scientific skills, or whether their avocational skills are used in their scientific work.

Derived from their autobiographical accounts on how individuals in all disciplines imagine their ideas when they work, Root-Bernstein, R. and M. (2001) compiled a core set of thirteen thinking tools that they argue are transdisciplinary.[27] These thinking tools are: visual thinking, abstracting, pattern recognition, pattern forming, kinesthetic thinking, empathizing, manipulating, modeling, analogizing, playing, dimensional thinking, transformational thinking, and aesthetics. This analysis informs my study as it can explain the ability of an individual to seriously engage in multiple activities by employing the same thinking tool across distinct activities. Music skills can thus inform mathematical and scientific thinking.

The reasons for the preoccupation of scientists with music have also been explored by neuroscientists, psychologists, philosophers and research scientists. Neuroscientists Schmithorst and Holland (2003) acknowledge that scientists and musicians use common areas of the brain– the ones typical to problem solving and visual thinking. Their studies, which involve functional MRIs, show that people who have been extensively engaged in music-making in their youth,

[27] Used across many disciplines.

exercise problem-solving and visual-thinking sections of the brain (that are also used by scientists) to much larger degrees than their non-musician counterparts. The Mozart effect, originated by Rauscher, Shaw, and Ky (1993), claims that short exposure to Mozart's music can enhance temporary spatial-temporal reasoning. Psychology articles (Hong, Whiston, and Milgram, 1993) speculate that activities that require substantial cognitive input combined with practice and one-on-one instruction such as playing an instrument, have a substantial affect on scientific thinking. They define scientific thinking as the kinds of thinking used in theory generation, experiment design, hypothesis testing, and data interpretation that involve methods of induction, deduction, analogy, analysis, and problem solving.

While the above anecdotal and experimental literature supports the potential sharing of mathematical and musical cognitive skills, a contrasting view, that of mathematical and musical intelligences being separate abilities, is raised by Gardner's (1993) theory of multiple intelligences. According to his theory, mathematical and musical intelligences are separate, as they each fulfill the criteria Gardner set for an ability to be considered a distinct module of intellectual ability: existence of exceptional individuals, set of core operations, distinct historical development, and evidence for the potential of isolation in localized areas of the brain (e.g., areas that are spared or compromised as a consequence of brain damage). As such, intelligences cannot participate in transfer across modules.

Continuing with the former line of thinking, which supports shared cognitive abilities, I chose to focus on the literature that discusses shared spatial/visual abilities and aesthetic abilities in the next section. My choice has been affected by studies showing significant correlations between music training and spatial/visual abilities as well as by the growing interest in aesthetics in computer science.

b. Specific Shared Cognitive Skills: Spatial/Visual and Aesthetics

As significant correlation is suggested between scientific success and visual abilities as well as between musical engagements and visual abilities (Root-Bernstein, Bernstein and Garnier, 1995), I explore in more detail the literature on spatial/visual abilities. Similarly, I explore the literature on aesthetics, as its common manifestations in science, music, and mathematics have been suggested by multiple researchers like Root-Bernstein, R. S. (2002, 1996), Wannamaker (2001), and Rothstein (1995).

i. Spatial/Visual Skills

This section discusses spatial/visual abilities in the scientific/mathematical domains as well as in the artistic/musical domains.

aa. Spatial/Visual Skills in Scientific and Math-based Disciplines

Spatial/visual ability, framed by Gardner (1993) as one of the multiple intelligences, has been shown to be as important as analytical ability and language (Arenheim, 1986), and useful in many scientific and math-based disciplines including engineering (Sorby, 2009), Chemistry (Barke, 1993), and computers (Norman, 1994).

According to Arenheim's (1986) *A Plea for Visual Thinking*, thinking is impossible without relying on perceptual images. He provides numerous examples that demonstrate the importance of visual ability, including the ability of chess players to retain whole games in their memories, which "does not rely on a mechanical copy of the arrangements of pieces on the board, preserved in eidetic imagination" (Arenheim, 1986, p. 494). Rather, it is visualized as "a highly dynamic network of relations in which each piece comes with its potential moves–the queen with her long, straight outreach, the knight with his crooked hop–and with the endangerments and protections of its particular position. Each piece is meaningfully held in its place by its function in the total strategy. Therefore any particular piece does not have to be remembered piecemeal which would be much more cumbersome" (Arenheim, 1986, p. 494).

Sorby (2009) found that spatial-skills training given to engineering freshman with poorly developed spatial/visual skills, resulted in higher grades and higher retention rates than engineering freshman with poorly developed spatial/visual skills who did not receive such training. Barke (1993) identified expectations of chemistry teachers of their students to recognize structural models of matter. As such he attempted to find out whether illustrations of such models are recognized as spatial by the students, and at what age does spatial/visual ability develop enough to be used to recognize such illustrations. Correlating the results of a special test of spatial/visual ability of interpreting two-dimensional drawings with the results of an intelligence test, he found that spatial/visual ability develops at around age of 14 and that boys perform better than girls. He encourages chemistry teachers to use such illustrations, as students will develop abilities to imagine crystal structures corresponding to given formulas of solids, and will be able to use their spatial/visual ability in other subjects like mathematics, physics, and geography.

Norman (1994) argues that working with computers is spatial, involving the pressing of buttons, setting switching and sliders, and arranging objects on a physical desk. He has shown spatial visualization ability to be a major cognitive correlate to human-computer interaction performance, and recommends trainings individuals with low spatial visualization ability on tasks that require spatial/visual reasoning. He also offers ways to enhance user interfaces by using spatial metaphors and analogies, graphical user interfaces, revealing hidden relationships through graphs and flow diagrams, and allowing users to directly manipulate objects.

Finally, Root Bernstein R. and M. (2001) have shown that visual thinking has been a central thinking tool in the discovery and development of scientific, technological and artistic advances that have had a long-term impact on society. For example, they bring in theoretical physicist Richard Feynman's (1918-1988) description of his mathematical thinking process: "Ordinarily I try to get the picture clearer, but in the end the mathematics can take over and be more efficient in communicating the idea of a picture. In certain particular problems that I have done, however, it was necessary to continue the development of the picture as the method before the mathematics could really be done" (Root-Bernstein, R. and M., 2001, p. 54).

Another example is Beethoven, who said, "I hear and see the image in front of me from every angle, as if it had been cast, and only the labor of writing it down remains" (Root-Bernstein, R. and M., 2001, p. 58).[28]

The above literature points out the importance of spatial/visual abilities in scientific and math-based fields through a combination of experimental studies and anecdotal evidence. The literature in the following two sections reports on the effects of music on spatial/visual abilities, focusing mainly on two musical aspects: music listening and active music learning. The majority of studies investigated the effects of listening on spatial/visual ability, but the most promising results are on the effects of musical training on the development of spatial/visual abilities.

bb. Spatial/Visual Skills and Music Listening

A pioneering study, known as the Mozart Effect, attempting to relate music listening to spatial reasoning, was conducted by Rauscher, Shaw, and Ky (1993). Three groups of 12 college students were presented with the same spatial-reasoning tests (using the *Stanford-Binet Intelligence Scale),* immediately following listening to a sonata by Mozart (first group), a

[28] Thayer, et al.'s publication *Thayer's Life of Beethoven, Part II* (1991), Princeton University publishers, reports in pp. 850-851, that Louis Schlosser, one of Beethoven's students, claimed Beethoven told him this quote.

relaxation tape (second group), and silence (third group). The results demonstrated a better performance in those who listened to the Mozart Sonata, claiming a causal relationship between music listening and spatial/visual ability, and leading to many attempts to replicate and expand on this study by using different Mozart music, non-Mozart music, or different spatial reasoning tests.

Hetland (2000a) conducted a meta-analysis of 31 experimental studies concerning the effects of music listening on spatial reasoning for adults. Her analysis revealed that enhancement of spatial reasoning is not limited to music by Mozart, but may include other kinds of classical music. Hui (2006) designed an experimental study to examine whether listening to any music by Mozart improves preschool children's spatial reasoning. A total of 41 preschool children were randomly assigned to six groups, with each group being presented with a sequence of a Mozart Piano Concerto, age-appropriate popular music, and silence, followed by a spatial reasoning test. The analysis of the results revealed no significant differences among the groups with respect to the music while controlling for the children's age. However, spatial reasoning scores increased for younger children relative to the older ones after listening to Mozart's music.

Schellenberg (2001) dismisses the studies on short-term effects of music listening on spatial/visual abilities, citing them as unreliable, and claims that these effects can be explained by the arousal of the listener's mood.

cc. Spatial/Visual Skills and Music Learning

Hetland (2000b), in her meta-analysis of 15 experimental studies investigating the relationship of music learning to spatial reasoning of children, found that active music instruction had an influence on children's spatial/visual abilities, and that music instruction based on standard notation resulted in greater spatial improvement than the instruction that was not based on music notation. These experiments were typically constructed with children 3-7 years old, with a treatment group that received 10-60 minutes of active music instruction (e.g., singing, listening, playing percussion instruments), 1-5 times per week for 1-36 months in duration, while the control groups received no instruction.

Gromko and Poorman (1998) showed in their experimental studies the effect of music training on preschoolers' performance IQ, particularly on spatial tasks. Their research was driven mostly by previously observed reliance of both spatial/visual and musical intelligence on sensorimotor experiences. In their study of 30 Montessori preschoolers (age three) which were split into a group that was trained in music weekly over a period of seven months, and one that was not, each group was presented with musical-spatial tasks of matching short melodies with graphic representations, and of drawing graphic representations of the contour of short melodies. The study showed that performance on all three measures improved with time and that each measure was significantly correlated with the other two. This study confirmed that children's musical ability is predictive of their ability to interpret and produce symbolic representations of music.

A similar study (Nelson and Barresi, 1989) but with spatial and musical analogical-reasoning tasks, showed that musical intellectual strategies improve with age, and that development in music parallels understanding of spatial concepts. To eliminate the possibility that the association between music and spatial tasks could be a consequence of age (the fact that older children performed better on both tasks), Lamb and Gregory (1993) have shown the same positive associations between reading and musical abilities, in two separate groups of five-year-old and nine-year-old children.

Schellenberg (2001), in contrast to his dismissal of the studies that pertain to short term effects of music listening on spatial aspects, opines that the effect of music instruction on non-musical aspects of cognitive development is still an open question and is worth investigating.

While the above studies show associations between music training and spatial/visual ability, Neuropsychological research on music processing (Peretz, 2001) has advocated for modularity of music perception and cognition. They also advocated for modularity of the individual aspects of music, such as the independent processing of melody and in different parts of the brain. Moreover, in studying brain-damaged patients with Amusia,[29] none has exhibited accompanying deficits in spatial/visual abilities, advocating independence of music ability from a spatial/visual one. For example, one of Peretz's Amusia patients could not discriminate tones that differed by gross differences in pitch, yet she continued to drive safely around Montreal (Peretz, 2001).

ii. Aesthetics

Aesthetics, the study of beauty and of those properties of a system that appeal to the senses (as opposed to the content, structures, or function of a system), is a type of knowledge that has been discussed mostly in the arts. For example, Leder et al. (2004), in trying to provide psychological explanations for general experiences that provide aesthetic pleasures, focuses only on art without any regard to science. They present a five-stage, information-processing model of aesthetic processing of perception, explicit classification, implicit classification, cognitive mastering, and evaluation, with examples taken from painting (e.g., Monet), music, and generalizations to other domains that do not mention science.

[29] A musical disorder that appears mainly as a defect in processing pitch, but can also affect musical memory and recognition.

While it is obvious to some people that artists in general possess a strong sense of aesthetics, it is surprising for them that scientists and mathematicians also share this trait. Root-Bernstein (2002; 1996), Rothstein (1995) and Wannamaker (2001) discuss shared aesthetics between mathematics/science and music.

Wannamaker (2001) introduces themes of aesthetics shared between mathematics/science and music, including simplicity versus complexity, discovery and surprise, and tension versus release. Aesthetics of simplicity versus complexity has been explored by mathematician, George David Birkhoff (1933), as a result of his interest in the structure of Western music and what makes something melodious. He came up with a formula for aesthetic measure, M = O/C, where "M" is an aesthetic measure, "O" is an aesthetic order, and "C" is complexity. This formula expresses the fact that high aesthetics exists as complexity decreases and orderliness increases. Birkhoff applied his formula to his own poetry and his formula later became useful in evaluating paintings and scientific discoveries.

A comparative aesthetics of simplicity versus complexity in mathematics and music is provided by Rothstein (1995) through mathematical proofs and classical compositions, respectively. He says a mathematical proof is elegant when it uses a minimum of additional assumptions, derives a result in a surprising way from unrelated theorem(s), is based on new insights, or the method of proof can be easily generalized to solve similar problems. Musical compositions in the Classical era, according to Rothstein (1995), also exhibit simplicity via their structural clarity and economy. Simplicity can be illustrated in the classical sonata form, which arranges musical ideas around a definite pattern: a short introduction; an exposition, which presents the main subjects, melodies, and themes of the piece; the development, which explores these ideas; the recapitulation, which is a repeat of the exposition; and a short, concluding coda. Musical variations, for example, exhibit economy in that a core theme serves as the basic material for the whole composition. Rothstein (1995) also talks about the shared aesthetics of discovery and surprise in mathematics and music, such as mathematician Gauss, who has described his feelings about succeeding to prove a theorem as a "sudden flash of lightning" (p. 136). This kind of sensation has been compared by the mathematician, Jacque Hadamard (1954), to sensations Mozart described–seeing his symphonies as whole in his mind before setting them down on paper.

Although one typically does not think of computer programs in terms of their aesthetics or elegance, programmers and computer scientists (Knuth, 1974; MacLennan, 2006) have given aesthetical considerations to the algorithms, software programs, programming languages, and user interfaces. For example, a short powerful program that clearly expresses the intent of the code can be considered beautiful, in contrast with code that is cryptic and unclear. In addition, the use of a recursive construct in a program, if possible, is considered more elegant than the use of loop iteration, when possible. As most software programs are typically large and complex structures, their creation must comply with principles of good organization in order to be comprehended, maintained, modified, customized, and ported across platforms, all which make it more efficient and less prone to errors.

Knuth (1974), a renowned computer scientist, said about computer programming that it is an art "especially because it produces objects of beauty" (Knuth, 1974, p. 673). In his classic series of books entitled *The Art of Programming*, he began advocating a practice of *literate programming* in which programs and their documentation are treated as works of literature.

Maclennan (2006), in comparing software engineering to structural engineering, as described by Billington (1985), identifies elegance as one of the three criteria for a good design of a software program. Similar to the design of towers and bridges, MacLennan believes that with many possible software designs satisfying the solutions to a software problem, the designs that "look good in fact are good" (Maclennan, 2006, pp. 3-4) (e.g., safe, efficient, and economical). A recent collection (Lammers, 2006) of programmers' own descriptions of the role of aesthetics in software programming demonstrates numerous analogies to the role aesthetics plays in artistic domains such as music, painting, and poetry. For example, a programmer comments that "if you write a program well, it's very elegant… it sings." (Lammers, 2006, p.120). A programming language designer said that "when you write an algorithm using M expressions, it's so beautiful you almost feel it could be framed and hung on a wall" (Lammers, 2006, p. 64). Yet another software designer commented: "Some people have different opinions about what makes the structure beautiful. There are purists who think only structured programming with certain very simple constructions, used in a very strict mathematical fashion, is beautiful, but to me, programs can be beautiful even if they do not follow those concepts, if they have other redeeming features. It's like comparing modern poetry with classical poetry" (Lammers, 2006, p. 13).

Elegance in software programming, according to MacLennan (2006), is equally important for designers as well as users of the software, as it promotes software that is technically superior as well as a pleasure to use, respectively. Moreover, elegant software instills confidence in its users, aiding in the user's understating of the software. It also helps users to develop an aesthetic taste for elegance in other software systems, thus encouraging the further development of elegant software and discouraging the inelegant.

Upon concluding the review of the literature concerning cognitive development (sections on Cognitive-Development Theories, Interaction of Genes and Environment in Cognitive Development, and on Cognitive Forces: Motivation and Flow) and the literature on a representative set of shared cognitive skills across the domains of music and science/math (section on Relations between Cognitive Skills of Scientists/Mathematicians and Artists/Musicians and section on Specific Shared Cognitive Skills), it is in place to discuss the literature that accounts for the potential transfer of cognitive skills across domains.

As will be shown in the following section, transfer of cognitive skills relies on abstraction of skills as well as on scaffolding, two of the concepts discussed earlier in the Cognitive-Development Theories section.

5. Skills Transfer

The literature on skills transfer explores the transfer of cognitive skills from a source domain to a target domain, and thus can contribute to my understanding of their possible transfer across the specific domains of computer science and music-making. The central construct in skill transfer theories has been analogical reasoning, which according to Gentner's structure-mapping theory of analogy (Gentner, 1983) is performed through structural similarities. His idea is that an analogy is a mapping of knowledge from a source domain to a target domain in which a system of relations that holds in the source domain also holds in the target domain. That implies that analogical reasoning denotes a preference for deep structure similarity in which only relations are mapped, and not for surface-structure similarity in which mostly element-attributes are mapped, or literal similarity in which both relations and element-attributes are mapped.

Holyoak and Thagard (1989) extended Gentner's idea of analogical reasoning in their multiconstraint theory to include semantic and pragmatic constraints in addition to structural constraints, all jointly driving the retrieval process in analogical reasoning. Using their theory, analogical reasoning proceeds in four steps: The first step occurs when the reasoner faces a task in the target domain; the second step, which is the access step, involves a superficial similarity in which the reasoner remembers a similar task in the source domain for which a solution or interpretation is known (more of a surface similarity); the third step, the mapping step, is Gentner's (1983) original structural mapping step of deep similarity; and the fourth step is the learning step, which reinforces the idea that analogical reasoning is guided by the purpose of the analogy.

Perkins and Salomon (1988, 1992) integrate analogical reasoning models in their transfer models and explain the emergence of similar skills in a target domain through their ongoing practice in the source domain. They distinguish between near transfer (i.e., learning across closely related domains) and far transfer (i.e., learning across different domains), and outline four specific conditions under which far transfer of a skill is enabled. First, the skill needs to be practiced extensively and in more than just the specific learning context. Second, and related to the first condition, transfer is fostered by the explicit abstraction of certain attributes from the source domain. Third, teaching people to reflect on their own thinking helps them later to recognize when to apply a source skill they have learned and also fosters far transfer. Fourth, the degree and quality of analogical relations that can be established between the source and target skills facilitates transfer.

With respect to the Perkins' and Salomon's (1988, 1992) second condition for far transfer, Gick and Holyoak (1983) have shown that with multiple contexts, learners are more likely to abstract the relevant features of concepts and develop a more flexible representation of knowledge. This resembles Root-Bernstein's (2001) idea of potential creativity in polymaths, to be discussed in the subsequent section. Through a serious of experiments, Gick and Holyoak (1983) have also shown that transfer from a source domain to a target domain is likely to be more successful if an abstract scheme (deep structure) is first developed from analogical reasoning of at least two examples within the source domain, rather than a direct transfer from an example in the source domain to the target domain.

Perkins and Salomon (1988, 1992) have also researched deliberate scaffolding mechanisms for far transfer. They suggested the "high road" (Perkins and Salomon, 1988, p. 25; Perkins and Salomon, 1992, p. 9) to transfer through a combination of two instructional strategies of bridging and hugging. In bridging,[30] the instructor uses analytical techniques of planning, deliberate making of abstractions, and searching for connections. In hugging, instructors try to engage students in reflecting on their past experiences from which they can then draw knowledge.

Additional transfer techniques such as the compare/contrast technique have been suggested by Bransford and Schwartz (1999) in which the mental act of comparison aligns multiple, structurally-similar cases and highlights the similar aspects of the cases. Bransford and Schwartz (1999) also came up with a model for Preparing For Learning (PFL) which goes beyond a direct application of knowledge via "knowing that" or "knowing how," but rather emphasizes "knowing with," (pp. 69-70) through interpretation and noticing, comparing and contrasting, and Perkins and Salomon's hugging and bridging (1988, 1992).

Bamberger and Disessa (2003) have used a multi-modal environment for practicing the development and subsequent transfer of music skills to more abstract spatial/visual skills along with scaffolding. In their computer-based environment, *Impromptu*, children developed and practiced a melodic music pattern-recognition skill and eventually were able to transfer it to a

[30] This concept of bridging is different from the "bridging" concept in Fisher and Bidell's (2006) model of Dynamic Skill Theory. Within this theory, a learner creates a bridge from a developed skill in a source domain to a target skill via analogical reasoning by creating a "shell" (hook) on which to hang future constructed knowledge.

more general pattern-recognition skill. This was accomplished by children listening to melodic lines while being guided by their teacher to simultaneously view their graphical display in pitch-contour representation (i.e., dots with no music staff[31]) and in standard music notation. Children were also encouraged to view the melodies' rhythm in multiple notations of beat attack, beat duration using bars, numerical beat duration, standard rhythm notation, and also to feel the rhythm using clapping. Thus, students could practice their music pattern-recognition skill in the two separate dimensions of rhythm and melody with auditory, visual, and kinesthetic representations enabling extensive practice in multiple contexts, which facilitates transfer. Bamberger and Disessa (2003) used *Impromptu*'s multi-modal representation of rhythm to teach children mathematical fractions.

The above literature on skills transfer illustrates the underlying theories of skills transfer along with their practice. With transdisciplinary engagement being associated in the literature with the potential for creativity (Root-Bernstein, 2001), the following section discusses literature on representative aspects of creativity. These include specific abilities and activities that are contributory to creativity, personality traits of creative individuals, social aspects of creativity, definitions of creativity, and the sensation of flow in creative experiences.

6. Creativity

Root-Bernstein (2001) suggests that individuals who continuously engage in transdisciplinary experiences are likely to possess some degree of creativity. This is attributed largely to their synosic[32] thinking in which they think and feel in multiple ways simultaneously,

[31] The staff is the set of five horizontal lines and four spaces, each of which represents a different musical pitch.

[32] Synosia is derived form *synaesthesis* and *gnosis*–the phenomenon of knowing and feeling simultaneously in a multi-modal, synthetic way.

a direct consequence of their transdisciplinary activities. With synosic thinking, these individuals continuously translate the intuitive forms in which their ideas appear in (e.g., visual images, aural patterns) to their corresponding formal descriptions in the specific domain. This process of knowledge translation is largely what makes up the generation of creative ideas: “to create is to combine, to connect, to analogize, to link and to transform” (Root Bernstein, 2001, p. 66). For example, musical mathematicians who can, for example, feel, hear, see as well as verbalize mathematical patterns in music, are polymaths who, according to Root-Bernstein (2001) habitually master aspects of the creative process across both domains, and thus have a higher probability of becoming creative than individuals who pursue a single domain.

Root-Bernstein, R. and M. (2001) recognize spatial/visual abilities as significantly contributing to creativity. In their book *Sparks of Genius* (2001), they provide biographical accounts of known innovators who reflect on their thinking process, which shows a reliance on visual images. These include scientists (e.g., physicist Richard Feynman, who used aural imaging, hearing and feeling the rhythmical nature of physics), artists (painter Georgia O’Keeffe (1887-1986), who created photograph-like images in her head), musicians (e.g., singer Luciano Pavarotti (1935-2007), who mentally stored musical images in his mind), and writers (e.g., Charles Dickens (1812-1870), who first “saw” his stories and then wrote them down).

Root-Bernstein, R. and M. (2001) and leisure researcher Kleiber (1999) also recognize playing and toying as contributing to creative thinking, as it allows one to explore through practicing, and also fosters analogizing and emphasizing through make-believe worlds. Root-Bernstein, R. and M. (2001) describe, for example, Feynman’s reflection on his deliberate work strategy of combining play with serious work: “Then I had another thought: Physics disgusts me a little bit now, but I used to enjoy doing physics. Why did I enjoy it? I used to play with it. I used to do what I felt like doing…" (p. 251).

Psychological factors and personality traits that contribute to creativity have also been discussed by developmental psychologists, including a nurturing family environment, a risk-taking personality, and a reflective personality.

Dacey and Lennon (1998) list 10 personality traits that are characteristic of creative personalities: tolerance of ambiguity, freedom to speak their mind, thinking outside the box, flexibility, willingness to take risks, preference for complexity, willingness to delay gratification, freedom from sex-role stereotyping,[33] perseverance, and courage. Out of these traits, they highlight tolerance of ambiguity as a significant marker for creativity, as it takes "a greater degree of strangeness or ambiguity to cause fear or terror" in such people than in others (Dacey and Lennon, 1998, p.99). As risk-takers, creative people engage in self-evaluation, as they own the self-confidence and inner direction to evaluate their actions, and typically rely on it at work (Dacey, 1989a).

Developmental psychologist Dacey (1989b), in his assessment of social factors of creativity, found out through his study of 100 New England adolescents of 56 families that households of creative people tend to be more nurturing and less discipline focused than other households. Through descriptions of the various parenting styles in households with evidence of creative ventures, he discovered that the parents are interested and focused on their children's behavior, though non-controlling, relying on conversations for instilling values, and using humor. Leisure development researcher Kleiber (1999), too, believes that parental support that promotes

[33] Implies being open to change (e.g., when creative males exhibit sensitivity to the feelings of others).

democracy and authoritativeness, but is not authoritarian, encourages independence while at the same time provides needed security and trust, fostering conditions for creativity.

Edwards (2008), in his book *Artscience: Creativity in the Post-Google Generation*, investigates the catalysts that drive the creative journey of innovative individuals who combine scientific and artistic disciplines. Such individuals are, for example, Diana Dabby, a concert pianist who became excited about electrical engineering, the field in which she subsequently pursued her doctorate applying chaos theory[34] to the automatic generation of musical variations of original pieces. Through his interviews with these individuals, Edwards concludes that such "artscientists" (Edwards, 2008, p. 10) are successful in translating ideas from one discipline to another partially because of their curiosity, knowledge, passion, ability to cope with failures, self-confidence, courage, and the freedom they have to explore their interests and realize their dreams.

In her work on creativity, which is mostly tuned to changes proposed in education of young children, Craft (2001) has developed the concept of "little 'c' creativity," that is, ordinary, life-wide creativity. She distinguishes it from "big 'C' creativity," which fundamentally changes knowledge within a domain and is enabled only by an extremely small group of talented people.

Finally, Csíkszentmihályi's (1996) definition of creativity is like Craft's idea of big 'C' creativity and is defined in terms of domain-changing creativity. Based on interviews with 91 internationally recognized creative people (e.g., Nobel physicist, John Bardeen (1908-1991); jazz musician, Oscar Peterson (1925-2007)), Csíkszentmihályi argues that creativity requires not only unusual individuals, but a certain culture and field of experts that can foster and

[34] Chaos theory is a field of study in mathematics that studies the behavior of dynamical systems that are highly sensitive to initial conditions. Chaos theory has applications in physics, engineering, economics, biology, and philosophy.

validate such creative work. Expanding on his previous work on flow (Csíkszentmihályi, 1990), he suggests that engaging in big 'C' domain-changing creative endeavors makes its agents fully immersed in the feeling of flow.

The literature reviewed so far in the previous sections has examined cognitive aspects of development with a focus on cognitive-development theories, shared cognitive skills between mathematicians and musicians, transfer of skills, and creativity. In addition to cognitive factors, it is possible that career- and leisure-related factors also play a role in combining computer science and music-making into a vocational/avocational framework. The following section explores that literature, including prevalent career and leisure development theories, relations between career and leisure, and the notion of serious leisure.

C. Adult Development of Career and Leisure

The work/leisure (or alternatively vocation/avocation) research field is interdisciplinary, with the leisure field being a relatively new field (beginning in the 1970s), focusing mainly on its relation to work. As such, the following literature review covers career development theories that can account for one's parallel engagement in a vocation and avocation, work/leisure relational theories, and the concept of serious leisure as distinct from casual leisure. This literature can help gain insights into the reasons (why) and process (how) of vocational and avocational choices that musical computer-scientists make.

1. Career Development Theories and their Accommodation of Leisure

A good subset of classic career-development theories, like Super's (Super, D., Savickas and Super, C., 1996; Swanson and Fouad, 1999), Holland's (Swanson and Fouad, 1999), Gottfredson's (Swanson and Fouad, 1999), Krumboltz's (Patton and McMahon, 1998; Swanson and Fouad, 1999), and Bandura's (Swanson and Fouad, 1999), is flexible enough to account also for the process of avocational developmental.

Super, D., Savickas and Super, C. (1996) and Super (Swanson and Fouad, 1999) discuss the ideas of multiple interactive roles assumed by people along their vocational developmental life span, and of role salience in which one or more roles can be central to an individual's life at any point in time. Role salience is composed of cognitive, behavioral, and affective dimensions and is thus reflected in the knowledge, participation, and commitment, respectively, that individuals have for any particular life role. Along Super's suggested five stages of growth (age 5-14), exploration (age 14-24), establishment (age 25-44), maintenance (age 45-65), and disengagement (over 65), a person can assume one or multiple concurrent roles (e.g., a worker and a parent), giving rise to the notion of avocational roles co-existing with vocational roles.

Holland's career-typology theory (Swanson and Fouad, 1999) is grounded in the attraction individuals have to environments (i.e., occupations and activities) that let them exercise their abilities, and express their attitudes and preferences for vocational or leisurely activities. Holland's theory is depicted with a hexagonal model of six personality types (Realistic, Investigative, Artistic, Social, Enterprising and Conventional), supporting the fact that a person can have multiple personality types, and therefore can engage in multiple environments in a vocation/avocation configuration. Following his initial hexagonal model, Holland devised a detailed, triple-letter code typology for vocations (e.g., the code **AIE,** suggests dominant[35]

[35] Characteristics' dominancy is indicated by the order of the letters. For example, a music teacher occupation is indicated with the **ASI** (Artistic/Social/Investigative) code emphasizing dominance of his or her artistic and social sides; while an actor occupation is indicated with the **AES** (Artistic/Enterprising/Social) emphasizing his/her artistic and enterprising sides but less his or her social side.

Artistic aspects combined with somewhat weaker possessions of **I**nvestigative and **E**nterprising characteristics, denoting jobs like writers).

Gottfredson (Swanson and Fouad, 1999) discusses the process of circumscription/compromise that an individual goes through as a result of the surrounding social and family environment, as suggested by the person-environment fit model of Holland (Swanson and Fouad, 1999). The idea of circumscription and compromise is the gradual convergence through progressive elimination on one's preferred vocational choices (circumscription), interleaved with the process of relinquishing the most preferred alternatives for the less compatible ones that are perceived as obtainable (compromise).

Holland's person-environment fit theory has been extended by Krumboltz's learning theory of career decisions (Patton and McMahon, 1998; Swanson and Fouad, 1999), trying to explain the process of person-environment fit with the incorporation of the learning and experience dimension: individuals learn about themselves through direct experiences (direct acting on the environment) or indirect experiences (external stimuli like perception), which ultimately result in a unique career path. This combination of experiences affects one's choice or elimination of a potential career, or its adaptation as an avocation.

Complementing Krumboltz's learning experiences dimension is Bandura's self-efficacy dimension of his social, cognitive career-theory (Swanson and Fouad, 1999). Self-efficacy involves one's belief in his or her ability to achieve and produce, as derived from past experiences like accomplishments, watching others, verbal persuasion, and emotional factors. As such, low self-efficacy can explain the restricted range of certain individuals' career options, making them occasionally push aside a potential career to the status of leisure activity.

As seen in the above literature review, common career-development theories can account for the inclusion of leisure. The following section examines the more recent literature on the relations between work and leisure whose seed was already planted in the 1940s.

2. Vocation/Avocation Reciprocal Relations

The bulk of the research literature on leisure focuses on its relation to work, with the hope to understand its effect on job satisfaction.

In the 1940s, Super (1940, 1941), along with his research on career development, developed a set of commonsense propositions about people's vocational/avocational likes and dislikes. He showed that avocations are manifestations of people's dominant interests, which are expressed, if feasible, in vocations of the same type, and otherwise in avocations, making them the source of satisfaction. His low-scale empirical study, which focused only on males, produced a set of propositions that relate extrinsic factors (e.g., monetary awards), intrinsic rewards (e.g., interests), vocation/avocation type resemblance, and vocation turnover to job satisfaction. For example, he proposed that: 1) People who believe their jobs are chosen for economic reasons or because of matched ability to training will derive more enjoyment from their avocations than from their vocation; 2) People who believe their job choice is motivated by their interests will derive more satisfaction from their vocation.

Super's initial empirical investigation of the nature of leisure and work was followed by additional empirical research performed by Adams and Stone (1977) on 100 business people, confirming that people who are unable to satisfy their achievement needs (i.e., their high desire for challenge, mastery of skills, control, praise, and recognition for achievement) on the job are likely to do so in their leisurely activities, more than those whose need for achievement is satisfied on the job.

Super's propositions prompted analytical studies by Parker and Wilensky (Veal, 2004), resulting in four work/leisure typologies on the relations between work and leisure: 1) compensatory relations of contrast between work and leisure in which work experiences are compensated for in a variety of unrelated non-work activities (e.g., an engineer who compensates for his stress on the job with his piano playing); 2) spillover relations of similarities between work and leisure, in which working experiences carry into free time; 3) segmentation relations (extension of compensatory relations), which denote a sharper split between work and leisure; and 4) fusion relations (extension of spillover relations) that specify mutual spillover influences between work and leisure in terms of skill development and levels of satisfaction.

Snir and Harpaz (2002) tested and confirmed variations of Wilensky and Parker's hypotheses on two 1,000 male/female participant samples across time (in 1981 and in 1993) from different socioeconomic areas with various educational backgrounds (e.g., primary school, university degree, technical/vocational education). Participants were classified as work- and leisure-oriented according to how central work or leisure was in their lives, according to their economic orientation (i.e., disposition to extrinsic work outcomes such as income), their intrinsic orientation (e.g., having an interesting job), and other factors. Snir and Harpaz (2002) confirmed that leisure spills over into work in that: the absolute work importance of leisure-oriented people is lower than that of work-oriented people (leisure-to-work spillover); that leisure-oriented people value more interpersonal relations at work than work-oriented people (leisure-to-work spillover); that leisure-oriented people prefer leisure over work as a source for intrinsic orientation (leisure-to-work spillover); and that as job satisfaction increases in value, the likelihood of being leisure-oriented will decrease (compensation for work by leisure).

Wilensky and Parker's hypotheses were also confirmed in Canada (Sharaf, 2008), in a study on Canadian public sector workers at the department of Canadian Heritage.[36] Sharaf found out that the degree of job satisfaction is directly linked to the "leisure appeal" (increased perceived sense of freedom and opportunity for achievement) offered at work (Sharaf, 2008, p. 3). She also found out that leisure spilled over to work as participants found enjoyment in some of the tasks performed on the job through tasks they enjoyed at home during leisure time.

In one of his studies on flow and creativity, Csíkszentmihályi (2008) demonstrated that flow experienced at work directly contributes to work satisfaction in the sense of being active, creative, focused, and motivated. In addition to work-induced flow, he showed that leisure-induced flow contributes to work when his study participants experienced several negative consequences after being asked to refrain from engaging in their favorite leisure activities. He also discusses music-making as a leisure activity that induces flow, and thus asserts its indirect contribution to productivity at work.

Haworth (2004), who explored the relationship between work, leisure, and happiness, has concluded through experiments that feelings of freedom of choice that are often perceived by people as being induced from leisure activities lead to feelings of enjoyment and therefore to happiness and well-being. He also asserts that leisure activities are instrumental in alleviating the negative psychological symptoms of unemployed people and keep retired people active.

Similarly, leisure researcher Zuzanek (2004) asserts that certain leisure activities (e.g., sports) can alleviate negative effects of time pressure and stress induced at work. However, she

[36] This department of the government of Canada has a responsibility to policies and programs regarding the arts, culture, media, communications networks, official languages, status of women, sports, and multiculturalism.

warns that leisure engagement may not be the remedy for all, as overworked people may benefit more from learning to control their time rather than from an extra activity.

In summary, the work/leisure literature examined in this section conveys relationships that can hold between work and leisure, as well as social and economic factors that could influence individuals' preferences of one over the other. The following literature zooms in on leisure, in particular on the notion of "serious leisure," which the avocation of music-making is typically associated with.

3. Serious Leisure

Although the traditional leisure literature has used the term "leisure" in its general sense, Stebbins (2004) unpacked it by differentiating the forms of leisure using different levels of intensity and duration across various social contexts. The literature in this section examines the characteristics of serious leisure, considerations for choosing music-making as serious leisure rather than a career, and the social aspects of collaborative music-making.

According to Stebbins (2004), serious leisure is "the systematic pursuit of an activity that is highly substantial, interesting, and fulfilling and where, in the typical case, participants find a career in acquiring and expressing a combination of its special skills, knowledge, and experience" (p.200). The adjective "serious" embodies qualities like earnestness, sincerity, importance, and carefulness. Leisure can range from casual, passing engagements, to intensive short term projects, to more serious lifetime commitments that can require a great deal of time, money, and energy.

Serious leisure is characterized by perseverance, availability of a career counterpart to the leisure activity, personal effort to gain skill/knowledge, personal and social identity (e.g., selfactualization, self-enrichment, self-expression, self-renewal, feelings of accomplishment, enhancement of self-image), social interaction/belongings, and lasting physical products of the activity (e.g., painting, music recording, scientific paper, piece of furniture). With this definition, serious leisure approximates work in the sense that it requires skills and active participation. The benefits of serious leisure include personal enrichment, social interaction, and renewal of one's self, and are also satisfying when weighed against the tension, dislikes, or disappointments sometimes involved in the leisure activity. Music-making can be viewed as serious leisure as it requires performance skills and continued practice, provides personal identity through self-accomplishment and through self-image, and offers social belonging through interaction with other musicians and with the audience. As stated by Stebbins (1989), "achieving even amateur status in music requires moderate amount of good training, steady practice, serious playing experience and native talent" (p. 228).

Nagel's (1987) empirical study on the alienation of music professionals from their vocational choice can facilitate understanding of why some individuals who planned to be musicians ultimately chose music as their avocation rather than their vocation. Based on Nagel's theory, it is possible that such individuals have ultimately chosen to alienate themselves from music as a vocation because of its low extrinsic rewards (e.g. monetary rewards), but decided to stick to it as serious leisure because it preserves the tie with their parents who supported them in their early musical activity. Nagel also identifies intrinsic reasons for a musician's alienation from music as a career: performance anxiety (e.g., memory lapses during concert performances, especially for soloists), fear of success, and envy.

Stebbins (1989) claims that "the essence of amateurism lies in the social and attitudinal organization of its practitioners" (p. 228). Through numerous conversations with amateur musicians in North America who participate in various musical groups, he explores the social network aspect between amateur and professional musicians, and amongst amateurs, looking at the structure of social relationships and their quality. Stebbins also notes that friendships can form within amateur musician's networks across class, race, and gender boundaries.

The social network of musical groups described by Stebbins (1989) resembles membership in a community. As such, I also explored Wenger's (1999) book *Communities of Practice: Learning, Meaning and Identity* in which he outlines a theory of learning and identity based on people participating in the social world. When people who have a common goal (a shared enterprise) actively engage with each other (mutually engage) via practice and knowledge sharing (shared repertoire), they are said to emerge and develop as a coherent community, which Wenger calls a Community of Practice. Members of a Community of Practice construct their meanings and identities by negotiating their participation in the community. This negotiation is an ongoing interplay between lived action (i.e., participation) and use of symbols or tools that embody the experiences of the community (i.e., reification). Newcomers usually assume peripheral participation but may subsequently be on a trajectory to full participation. Even though the notion of a community of practice connotes a flavor of geographical proximity, the geography of practice cannot be reduced to geographical proximity.

The literature reviewed so far has focused on the literature on the relationships between scientific/mathematic and music disciplines, which motivated my study (section on Relating Scientific/Mathematical and Musical Disciplines), and on two of the areas that make up the domain of my study: cognitive development and skills (Cognitive Studies section) and career/leisure development (Adult Development of Career and Leisure section). The following section discusses the literature on research paradigms and the tools I considered for arriving at the meaning of music-making through the lens of these areas of study.

D. Research

In this section, I review the literature that helped me converge on the overall research paradigm used in my study as well as the specific research strategy and methods. I begin with the literature on research paradigms and methods, and conclude with literature on discourse analysis and sociolinguistic analysis for researching narratives. The literature I used for the write-up of this study (Heller, 2006a; 2006b; Heller, 1997; Levi, 1995; Orwell, 1984) is described in the following Methodology chapter.

1. Research Paradigms and Methods

A useful, funnel-like framework that urges the researcher first to consider his knowledge paradigms prior to converging on the most applicable research methodology is given in the first chapter of Creswell's (2003) *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches,* called "A Framework for Design." As such, the funneling begins with the knowledge claim, which is the researcher's theoretical perspective, in other words, the underlying assumptions of what and how the researcher plans to learn. Creswell discusses four such types of knowledge paradigms: the postpositivistic/scientific paradigm described below by Phillips and Burbules (2000), the socially constructed paradigm, the advocacy/participatory paradigm, and the pragmatic knowledge paradigm. For example, if the goal of the research is to prove a theory or perform quantitative research, then a postpositivistic/scientific paradigm can be considered by the researcher; however, if the goal of the research is to construct meaning, then the appropriate knowledge paradigm is a socially constructed approach through interaction with a human community, entailing ethnographic or phenomenological research strategies.

Phillips and Burbules (2000) propose post-positivism, one of the four knowledge claims discussed by Creswell (2003), as the underlying knowledge paradigm for disciplined educational research. Broadening the positivist[37] narrow view that seeks the absolute truth and studies observable things, post-positivism accepts the coexistence of multiple truths, provides a framework for dealing with contradictions and imperfect knowledge, and affords the study of non-observable things like feelings. While these extensions to positivism seem attractive to my research, post-positivism also thrives to create causal relations: "…it seeks to develop relevant true statements–ones that can serve to explain the situation that is of concern or that describe the causal relationships that are the focus of interest" (Creswell, 2003, p. 38). As such, it does not align with my primary research interest of searching for and constructing meaning.

Mathematician and philosopher, Edmund Husserl (1999), laid down the philosophical foundations of phenomenology. In his lecture notes on transcendental logic,[38] he calls for the return to the pure sense of science, which he terms logic, in order to "…bring to the light of day the essential forms of genuine knowledge and science in all their fundamental shapes, as well as the essential presuppositions to which they are bound…" (Husserl, 1999, pp. 1-2).

He also believes that true knowing exists by going beyond (i.e., transcending) the lived experience to its essential being, as "only transcendental logic allows one to understand completely that the positive sciences can only bring about a relative, one-sided rationality"

[37] A philosophy of science based on the view that in the social as well as natural sciences information is derived from sensory experience, and that logical and mathematical treatments of such data are the exclusive source of authoritative knowledge.

[38] The study of the mind with reference to its perceptions of external objects and to the objective truth of such perceptions.

(1999, p. 7). Using the example of a table, Husserl distinguishes between the idea of the table (i.e., noema) and the being of the table itself (noesis). According to phenomenological philosophy, the latter, the noesis can only be known through the former, the noema, and the former can only exist because of the latter. Thus, the true knowing of a human phenomenon can be achieved only through the lived experiences of those who experienced it, and meaning is created when the object, as it appears in our consciousness, mingles with the object in nature.

Moustakas (1994) used Husserl's (1999) ideas on transcendental phenomenology in his framework for phenomenological research, a socially constructed knowledge claim (Creswell, 2003). Moustakas (1994) provides a description of the use of phenomenology as a qualitative research strategy along with its special data collection and analysis methods (Moustakas, p.103), which typically involve long, open-ended interviews aiming to capture the richness and complexity of experiences. In order to achieve going "back to the things themselves," Moustakas, focuses on bracketing (epoch), the ongoing process of putting aside presuppositions or biases of beliefs held about the world (Moustakas, 1994, p. 26). Part of phenomenological analysis is the process of horizonalization (or horizontalization), in which the researcher extracts significant statements from the told experiences, and organizes them into meaning units, which are then clustered into themes used for developing the textural descriptions of what was experienced and structural description of how it was experienced. The final step in the phenomenological research is the synthesis of meanings and essence by the reader of a phenomenological report.

Reinhartz and Davidman (1992) discuss feminist approaches to research typically used for bringing out the voices of women, or to study topics formerly ignored by social science. These approaches are associated with the advocacy knowledge paradigm (Creswell, 2003) whose underlying cause is the advancement of an action agenda for change. Liberating the concept of interview, Reinhartz and Davidman portray the feminist interview not through the common image of a superior assessing the qualifications of another person or eliciting of facts or opinions. Rather, they portray it as a world of interaction, cooperation, and participation that creates meaning and constructs data for both the interviewer and the interviewee. Such interaction often requires a lot of trust from the interviewer that the discussion is led in a fruitful direction and may even lure the interviewer to disclose personal experiences in order to gain trust. Feminist research methods are typically diverse, based mostly on qualitative principles, and use conscious-raising methods (small group discussions with no leader or imposed theme), sharing and analysis of group diaries and photos, drama therapy, conversations, and action agenda for a potential reform that may change the lives of the participants.

Both Heller (1997) and Dyson (1989) have performed ethnographic research in literacy studies. Through her participation in a women's writing workshop, in one of San Francisco's most distressed neighborhood of the Tenderloin, Heller (1997) not only advocates for these women but also contributes to studies in critical literacy. Through these women's personal stories and their interactions over an extended period of time, Heller brings out themes associated with critical literacy: importance of supportive facilitators, feedback, revision, and gentle criticism as well as revelations that writing can start out messy and end up neat and cohesive.

Like Heller's, Dyson's (1989) *Multiple Worlds of Child Writers: Friends Learning to Write* (1989), is another ethnographical study of literacy, but in this instance, of young writers. Through her observations of children's interactions in the classroom (e.g., their telling of adventure stories and fantasy characters) over an extended period of time, Dyson observes that children's writing, which at times looks like a mere collection of random ideas, is actually a coherent representation of their constantly changing view of their world, and their relationship to the surrounding social and symbolic worlds. For example, they integrate imaginary worlds with real ones and therefore may mix time dimensions such as present and past tense. Through her study, she advocates the need to recognize the existence and meaning of these "unstable" worlds in children's lives, and thus not to expect the perfection of unified text worlds. She also concludes that children's writing is initially integrated with talk and a lot of drawing used to explore language and make meanings, but over time changes to be less centered on drawing and more focused around text and talk.

Creswell (1998) guides the researcher through the journey of identifying the appropriate research methodology for his or her study by providing an in-depth analysis for each of the five research traditions within qualitative research: biography, phenomenology, grounded theory, ethnography, and case study. Each tradition is described along with its origin, underlying philosophy, variations, associated data collection and analysis methods, and challenges. Through a comparative approach with numerous, concise textual and tabular comparisons across the traditions, Creswell enables the novice researcher to quickly get the big picture and apply his or her criteria for choosing the appropriate method. Creswell does not neglect to discuss issues related to the write-up of the research study for each tradition, including its overall architecture, intended audience, and rhetorical devices (e.g. presentation of a key event in a biography versus scenes in an ethnographical study).

A more researcher-oriented framework for conducting qualitative research than Creswell's (1998) methodology-centered framework is provided by Glesne (1999). Through a micro-level view of the interview process, she reasons and provides tips for the logistic aspects of the interview, (e.g., site selection), for developing good interview questions (e.g., avoiding concatenated questions), and for the conduct of the interview (e.g., establishing rapport with the researched).

The literature in this section provides a road map and insights for arriving at the appropriate research strategies (e.g. phenomenology, ethnography) and data collection tools (e.g., interviews). The literature in the following section discusses methods for analyzing a specific form of data, called narrative (i.e., a form of story) in which people tend to communicate their experiences, typically through interviews, conversations, autobiographies, etc.

2. Analysis of Narratives

Narrative analysis looks at written or spoken communication (i.e., discourse) similarly to the way linguistics views the syntax (i.e., structure), semantics (i.e., meaning), and pragmatics (i.e., context, world knowledge, common sense) of a sentence. The literature in this section examines structural, contextual (i.e., sociolinguistic), and interactional approaches to the analysis of narratives. Application of these approaches can facilitate the extraction of the meanings underlying the texts of the narratives.

Structural analysis of narratives is valuable, as their structure reveals what is significant to the narrator about various ideas, characters, places, and objects. A comprehensive structural and temporal analysis of oral narratives of personal experience is provided by Labov (1997), using definitions and theorems. Labov shows that such narratives are typically bound by an introductory clause (like the abstract in a paper) and a coda, a statement that returns the temporal setting to the present. In between the introductory and coda statements, there are orientation statements that establish the characters, time and place, and evaluation statements, which provide information on consequences of events. Labov suggests that narrative construction requires a personal theory of causality, in which the narrator first selects the "most reportable event" (Labov, 1997, pp. 9-11) (an event less common than any other in the narrative, and is evaluated most strongly). Then the narrator selects a prior event, which caused that most reportable event, repeating this process until an event is reached for in which there is no further basis to ask the question "how did that happen?" Labov also explains special constructs like the assignment of blame/praise, and viewpoint (i.e., transfer of experience from narrator to listener) through a chain of causality established in the narrative.

Linde (1993), in her structural analysis of narratives, focuses on the notion of coherence as a "cooperative achievement of the speaker and the addressee" (Linde, 1993, p. 12). As such, she describes narrative strategies for achieving "adequate causality" through "a chain of causality that is acceptable by addressees as a good reason for some particular event or sequence of events" (Linde, p. 127). Linde also suggests narrative strategies for accounting for discontinuity in narratives when there is, for example, inadequate causality. One such strategy is the strategy of "apparent break" (p. 152), in which the speaker reconciles a seeming break by showing that the break is only apparent (e.g., a narrative segment in which a job interviewee is providing the shared characteristics of a previously narrated sequence of unanticipated held professions (pp. 152-153)). In addition to her pursuit of structure, Linde discusses the functionality of narratives in the creating, maintaining, and negotiating of identity.

Gee (1999), a sociolinguist, studies language in context, as combined with social and cultural contexts. He developed a discourse analysis theory based on the construct of discourse models, which are theories or assumptions about things in the world that can explain "why words have the various situated meanings they do" (Gee, 1999, p. 95). Analysis of text can thus be accomplished by identifying relationships between words or phrases, identifying the situated meanings of these words and phrases, and determining the discourse models implied by the situated meanings. Gee's discourse analysis has been used in the analysis of personal narratives of a group of craft-artists in Mishler's *Storylines* (2004) for the co-construction of their identity trajectories. Mishler first used Gee's linguistic device of stanzas (blocks) to syntactically structure their narratives, and then applied situated meanings and contextual discourse models to co-construct their identities. Through his discourse analysis, Mishler demonstrates the shifting of their identities over time, by identifying turning points in their life (e.g., personal events like marriage) that caused a shift in their life direction.

Schifrin (1996), too, applies sociolinguistic devices in the analysis of narratives and conversations. In her analysis of conversations of troublesome familial issues, Schiffrin demonstrates how such devices can be used to discover the tellers' agentive (action-oriented) and epistemic (belief-oriented) selves, social identity, and their position within the family (e.g., providing autonomy vs. dominating, expressing solidarity vs. distance). For example, she uses microanalysis of specific words (e.g., the pronoun "them" as in "she wouldn't go out with them") to denote the separation between groups. She uses other higher-level linguistic devices, like the use of indirectly reported speech,[39] as when parents report their daughter's belief of intermarriage between Jews and Gentiles, through "she said that they're just different," where "they" refers to Gentiles. By making their daughter be the author of beliefs they hold, the parents can afford not to directly express their own view about intermarriage, through transmitting it indirectly.

[39] Expressing the content of utterances without quoting them explicitly as is done in direct speech. For example, *He said, "I'm coming"* is direct speech, whereas *He said he was coming* is indirect speech.

A more interactional approach to the analysis of narratives is offered by Davies and Harré (1999) through their construct of positioning. The notion of positioning is similar to the notion of a role in a conversation. However, while roles "serve to highlight static, formal, ritualistic aspects of encounters," positioning, as its spatial connotation indicates, is more dynamic and flexible, with the potential to shift during a conversation (Davies and Harré, 1999, p. 33). The shifts are based on what is said by the participants in the conversation: we explain our positions, defend them or alter them. We also try to position others, as, for example, wrong or right, competent or incompetent. These positions will be tried out and abandoned or maintained, depending upon the outcomes they generate.

While the notion of positioning (Davies and Harré, 1999) was originally intended for the understanding of oral conversations, Bamberg (1997) demonstrates the notion of positioning in written narratives, treating the narratives as performances with characters. Using Labov's (1997) theory of narrative structure, Bamberg identifies three different levels in which positioning can occur in a narrative: the positioning of the narrative characters in relation to one another within a reported event (e.g., marking the agent of an action inflicted upon someone else); positioning of the narrator to the audience (e.g., seeking to position oneself as an expert on a topic); the positioning of the narrator to himself (e.g., how do I want to be understood?). Using teenagers' accounts of their sexual identity, Bamberg shows that two different narrative accounts of the same experience demonstrate different positioning for the same characters, resulting in different ideas. Moreover, they also result in different moral positions and identity claims, thus broadening Labov's ideas on the assignment of blame or praise and viewpoint.

In addition to positioning, there are other interactional constructs that have been used to analyze discourse, such as footing and voice. Ribeiro (2006) compares the uses of positioning, footing and voice, explaining that while positioning is a strategic interactional move of the participants in a conversation, footing denotes more subtle shifts of the alignment of the participants in a conversation. Voice denotes how participants in conversation express their agency. Her clarifications are illustrated with real life conversational examples (e.g., brothers' phone conversation about the medical situation of their parents). In her analysis of conversations, Ribeiro also employs the structure of frame, which denotes the meaning people assign to what is said in the conversation (i.e., what is going on, what is being done). For example, it helps to know if in the brothers' conversation the brothers are engaged in a legal, medical, or social conversation.

In this literature review, I have explored the mathematical literature on music, which contributed to the motivation of my study, as well as the three areas that make up the domain of my study: cognitive development and cognitive skills, career and leisure development, and research. As illustrated, the mathematical literature focuses on the pursuit of mathematical phenomena in music, but does not account for the tendencies and capacities of the individuals who pursue it. This realization contributed to my decision to have a deeper look at the individuals themselves who combine such worlds through the lens of their cognitive makeup and career and leisure considerations, as represented in their narratives.

The following chapter on methodology describes my research paradigm and specific data-collection and analysis methods for obtaining that deeper look.

III. Chapter Three: Methodology

In this chapter, I outline my methodology for uncovering how music-making is situated in the lives of computer scientists who keep serious music-making in the center of their lives.[40] I begin with my general methodological approach for obtaining the answers to the research questions presented in the introductory chapter, along with the rationales for the approach. I proceed with descriptions and reflections on my data collection methods, my methods for the thematic analysis of the collected data, and with my approach to the write-up presentation of my analysis. I conclude with what I have learned from the pilot study I conducted for testing and validating portions of my methodology.

A. General Methodological Approach: Phenomenological Case Study with Sociolinguistic Analysis

The aim of my study is to uncover and describe the meaning of the phenomenon of music-making in the lives of computer scientists who persist with serious classical music-making. I want to enter these people's lived experiences, and understand their perspectives of this phenomenon to provide a rich, textured description of their experiences. I believe that people construct meaning in their lives through their interactions within their social and cultural contexts, and that I, as a researcher, can co-construct with these individuals the meaning they assign to their parallel engagement in computer science and music-making.

Contemplating the design of my research study, I followed Creswell's (2003) suggested considerations for approaching research inquiry that help assess and converge on research methods: the researcher's general knowledge paradigms, strategies of inquiry and the specific

[40] My study focuses on professional computer scientists who engage in the avocational activities of playing classical music such as practice and performance.

research methods. First, with respect to knowledge paradigms, which are the theories and philosophical stances the researcher takes on ways of knowing, I approach my study with no preliminary formal theories regarding the meaning to be uncovered, although I admit to having some informal expectations, such as the presence of career conflicts between music and computer science, that I put aside for the duration of the study. I also do not seek to capture cause-effect relationships or correlational ties within constituents in my study. As such, my knowledge paradigm for this study does not follow a positivist tradition, or as defined by Creswell (2003), even a post-positivist tradition (Phillips and Burbules, 2000), which is theory-centered, and whose essence is a deterministic philosophy of causes determining outcomes, is a reductionist- or even a numerical-oriented approach to ideas. Neither does my knowledge paradigm follow an advocacy approach of bringing out the voices of a marginalized group (Reinhartz and Davidman, 1992) for the purpose of bringing about a political change or social justice. As previously stated, my knowledge paradigm for this study is based on the premise that people make sense of the world they live in within their social and cultural contexts. As phrased by Creswell (2003), "individuals seek understanding of the world in which they live and work. They develop subjective meanings of their experiences–meanings directed toward certain objects or things. These meanings are varied and multiple, leading the researcher to look for the complexity of views rather than aiming to narrow meaning into a few categories or ideas" (p. 9).

As such, I believe that I, the researcher, can capture the meanings individuals assign to their lived experiences through observing and participating with them in such experiences, or through their telling of these experiences.

Second, this type of socially constructed knowledge implies the employment of a qualitative research strategy rather than a quantitative one. More specifically, it entails an either ethnographic or phenomenological study out of the five traditions of research inquiries specified by Creswell (1998).

Framing my inquiry as a phenomenological case study using a collective case study of several computer scientists who all experienced the phenomenon of engaging in classical music in parallel to their work, enabled me to gain insight into people's individual experiences of this phenomenon, and through my ongoing analysis of their stories, derive its essence. At one point, I considered an ethnographic study, in which I would situate myself in the actual environment where my study participants engaged in musical activities, such as the monthly soirées of the Boston Piano Amateurs Association (BPAA),[41] the rehearsals and performances of the semi-professional Boston Philharmonic Orchestra (BPO),[42] or at a local gathering of The Chamber Music Network (ACMP).[43] In such settings, I could be a participant observer for an extended period of time, observing my study participants in their natural setting of music-making, technical discussions, and social interactions. I have been intrigued by the depth captured in such studies like Dyson's (Dyson, 1989) and Heller's (Heller, 1997), both of which combine ethnographic studies with extended interviews of the individuals who are part of the culture studied in their ethnography. However, since it is not the culture of musical groups that I am after but rather the essence of the phenomenon of certain individuals making music in parallel to their work, I abandoned the ethnographical approach in favor of a phenomenological

[41] Boston Piano Amateurs Association (BPAA), founded in 2001, provides performance opportunities, master classes, competitions, and workshops for adult amateur pianists. BPAA participants meet on a regular basis in musical soirees (a social gathering with a musical playing, discussion and a reception).

[42] Boston Philharmonic Orchestra (BPO), founded in 1979, consists of 96 players, including amateurs, students and professionals. Among the amateurs are doctors, lawyers, teachers, and computer professionals. BPO's conductor is Benjamin Zander.

[43] ACMP, the Chamber Music Network (formerly known as the Amateur Chamber Music Players) is a non-profit association that facilitates informal playing and singing by people of all ages and nationalities, beginners to professionals. Meetings are typically at schools.

collective case study. Nevertheless, I included in my study observations of such musical meeting places (e.g., BPAA meetings) as well as the workplace of some participants for contextualizing their told experiences.

Phenomenology is the study of the essence of an experience. Phenomenologists (Moustakas, 1994; Husserl, 1999) believe that knowledge and understanding are embedded in our everyday world and that this knowledge cannot be quantified or reduced to numbers. They believe that truth and understanding of life emerges from people's disciplined descriptions of their life experiences rather than explanations of these experiences. In Moustakas's book, *Phenomenological Research Methods*, mathematician and philosopher, Edmund Husserl (1859-1938) who is considered the father of phenomenology, hypothesizes that meaning is uncovered only when one can turn to the "things themselves" (Moustakas, 1994, p. 26) (i.e., the things of consciousness as they appear inside our heads) via memory and imagery. That means that the only true knowing of a phenomenon occurs when one can relive the world in which the phenomenon/experience was lived, a pre-reflective world that takes place before one thinks about it or puts it into language. This way of knowing through lived experiences assumes that our consciousness is always directed at and perceives some "thing" (the intentionality of our consciousness). This way, one's external perception of a thing (the noema) and the internal perception of the thing being perceived (the noesis) cannot exist in isolation: the thing (or phenomenon) can be known only through experiencing it, and one's experience of the thing (or phenomenon) exists only because of the being-ness of the thing (or phenomenon). This philosophy on the structure of consciousness has been adapted as a phenomenological approach to qualitative inquiry (Moustakas, 1994; Creswell, 1998), in which individuals comprise a collective case study with which to study a phenomenon, and must be carefully chosen as having experienced the phenomenon.

In phenomenological research, the researcher has a personal interest in the research question, but needs to "bracket" (or epoche, meaning "stay away from") his or her own experiences and preconceptions about the phenomenon and understand it only through the lived experiences told by the study participants. Bracketing is challenging since it assumes that researchers can separate their personal knowledge from their life experiences. I attempted bracketing via multiple iterations of in-depth reflective practice of my own experiences of the phenomenon of music-making as a computer scientist, introducing them into my study. Making my experiences and reflections explicit helped me come to terms with them rather than ignore them (Moustakas, 1994).

Part of my phenomenological data analysis methodology is a discourse analysis strategy of sociolinguistic data analysis (Gee, 1999; Schiffrin, 1996), which I applied in my study to a limited extent.[44] Sociolinguistic data analysis is a discourse analysis approach that is applied to the analysis of written and spoken language, and studies language as influenced by social and cultural factors such as age, gender, ethnicity, class, religion, education, race, etc. Sociolinguistic analysis utilizes both the form (e.g., grammar, semantics) and function of language (language as a social phenomenon) to extract meaning from the words used. Researchers in the social sciences (Mishler, 2004; Schiffrin, 1996; Bamberg, 1997) maintain that only through a narrative, a discursive representation of acting in the world, can we make sense of our experiences in life and who we are in the social world. Since I, too, believe that words and thoughts are closely tied, I apply sociolinguistic analysis methodology to yield as

[44] Applying a limited sociolinguistic analysis to the narratives in this study facilitated the thematic analysis. However, a more robust sociolinguistic analysis would have drawn attention away from the primary research objectives of this study.

close as possible the intended underlying meanings of the experiences told in the narratives and interactions created throughout the interviews. It is important to note that sociolinguistic analysis is typically interwoven as part of the thematic analysis, thus it is not necessarily possible to isolate it from the rest of the thematic analysis of the narratives.

In applying sociolinguistic analysis to the narratives told by my study participants, I relied on some of the structural narrative analysis as offered by Linde (1993) and Labov (1997). Their analysis facilitates understanding of narratives as it helps to identify the various units of the narrative, their function, and interrelations between these units. Some of these units are the introductory statement(s), orientation and factual statements, evaluative statements such as assignment of praise or blame to the protagonist or other characters in the narrative, causality chains, chronological relations, the most significant event in the narrative, and the summary coda unit.

In addition, I apply sociolinguistic analysis techniques not only to the narratives told by the interviewees, but also to the overall interactional dialogue involving the interviewees and me, the interviewer. Regarding the interview as a dialogue allows me to pay attention to the co-construction of the experiences told in the narrative through the dialogic exchange between the interviewer and the interviewee. It enables me to view the interview as co-constructed by the dialogue participants through the weaving of their positioning, a concept first introduced by Harré (Davies and Harré, 1999) and subsequently clarified and applied by sociolinguists Schiffrin (1996), Bamberg (1997), and Ribeiro (2006) in narrative analysis. Positioning, according to Davies and Harré, is a dynamic process of conversational shifts. These shifts are driven by what is said by the participants in the conversation and serve to position one another within a conversation. Positioning can occur in two modes. The first mode is when what one person says positions another person (i.e., interactive positioning), such as when one person positions another as right or wrong, competent or incompetent, knowledgeable or not. The second mode is when one positions oneself (i.e., reflexive positioning), such as when one explains his or her own positions, defends them, or alters them. In both cases, positions are tried out and then abandoned or maintained, depending upon the outcomes they generate. I have occasionally used positioning, especially when characterizing aspects of the participants (e.g., a participant positions him/herself as curious, motivated, and diligent), which proved to be contributory to the thematic analysis as it explained, for example, the ability of certain individuals to be in the forefront of interdisciplinary inventions.

Sociolinguistic analysis of narratives has been used by Mishler (2004) to construct the identities of crafts people. Schiffrin (1996) and Bamberg (1997) look at how individuals establish themselves and their experiences through their life stories by paying attention to the language, social manifestations and conversational stances employed by the co-participants in the storytelling (i.e., the narrator and the characters in the story). Schiffrin (1996) also uses sociolinguistic analysis to show how aspects of language can reveal one's beliefs and desires as well as one's actions, and how these beliefs, desires and actions may sometimes conflict with each other. In her analysis of intermarriage narratives, for example, Schiffrin discusses the possible roles of the pronoun "one," in which "one" within the phrase "she'd never go out with one again" refers to a group (i.e., the group of gentiles) rather than an individual, thus affecting the meaning of the phrase (p. 179).

Sociolinguistic analysis requires careful reading and interpretation of the textual material, with interpretation supported by linguistic evidence. The highly interactional and inferential nature of this type of analysis suggests the need for the researcher to be highly sensitive to the nuances of the text. This presents me, the researcher, with a difficult challenge, which is the risk of over- or mis- interpreting words used in the narratives by the interviewees, and not staying faithful to the experience as described by the interviewees. I overcame these challenges not by constraining my interpretations but rather by not being overly definitive about my discovered interpretations and by questioning their validity. I also validated some of my interpretations with my study participants.

Finally, my specific methods for data collection, as entailed by the inquiry strategy of phenomenological study, include interactive, open-ended interview questions for eliciting interview data in the form of spoken narratives, along with additional documents and observational data. My data analysis methods included thematic analysis of these narratives integrated with sociolinguistic analysis. The applications of these data collection and analysis methods are described in detail in the subsequent sections.

B. Collecting Phenomenological Data

In this section I describe the process of recruiting the study participants, the process of collecting data and the types of data collected.

1. Study Participants: Recruitment and Challenges

Once I determined my research strategy of a phenomenological collective case study, I began recruiting study participants. Qualifications for recruiting study participants denoted individuals who work (or have worked) as computer scientists[45] for a minimum period of ten

[45] In addition to programming, a computer scientist also typically works on the theoretical side of computer systems such as algorithm and data structure development and design, software engineering, systems architecture,

years, and who have been playing classical music in parallel to their computer-science employment as their serious avocation. Formal degrees in computer science (or their mathematics equivalence for the more senior participants) were not required, though desired.

I have recruited nine participants, whose names have been changed for privacy reasons per a signed privacy agreement (see Informed Consent form in the Appendix section). I have allocated the first two individuals, (David, euphonium/baritone player; Martin, pianist), 60-80 years old, for the pilot study which preceded the actual study and is discussed in the Pilot Study section of this chapter. The seven participants for my actual research study included two females and five males, 40-80 years old: Meg (flutist), Delia (pianist), Stan (timpanist), Ernie (clarinetist), Ethan (oboist), Miro (pianist), and Sol (pianist). The relatively small female-to-male ratio reflects the reported small female-to-male ratio of computer-science graduates in the western world, let alone female computer scientists in the workforce who also seriously play a musical instrument. Apart for gender variability, I did not attempt to vary the participants in terms of social class, age, or demography although introducing such variability could be a basis for additional research. However, for purposes of reporting, five participants were born and live in the US, one participant is Israeli-born who immigrated to the US in his youth, and one participant is Israeli. Six out of the seven participants have formal university degrees in computer science (or the mathematics equivalence), with four out of these six also holding a formal classical-music performance degree (with one being a minor degree in music performance).

information theory, database theory, computational complexity theory, human-computer interaction, numerical analysis, programming language theory, speech recognition, computer graphics, and computer vision, etc.

I reached out to potential participants through a combination of my own contacts with musical computer-scientists, through word-of-mouth and through formal announcements of my study. I began with spreading the word about my research study and the profile of sought-after participants in passing among friends and acquaintances in social gatherings. This brought about spontaneous recollections of potentially matching people with whom I then followed as study participants. Following the recommendation of a former colleague of mine, a pilot participant in my study, I was introduced to members of BPAA at one of their monthly soirees. A blast email from their president yielded numerous responses, from which I recruited one participant. Within a short time, I reached the number of participants I allocated for my pilot study and actual study (two via personal contacts, five via word-of-mouth, two via formal announcements), reserving the remainder of potential interested participants for future research studies.

My initial challenge in recruiting study participants was obtaining responsive and interested participants as I wanted people who were looking forward to telling their stories. Although I was aware of the potential availability of a significant number of individuals with the desired qualifications through my own contacts as a computer scientist and musician, I was uncertain about their desire to be interviewed on the meaning of music-making in their lives. However, this initial concern was quickly dismissed as potential interviewees expressed genuine interest and enthusiasm to share this facet of their lives, as became evident through their various email and phone communication (e.g., *Would be delighted to meet with you* (David, personal communication, December 9, 2010); *Sounds very interesting. Yes. I'd be happy to talk to you about this* (Ernie, personal communication, December 10, 2010); *I would be happy to help in any way with your research* (Ethan, personal communication, January 22, 2011); *I received your forwarded email. I would like to participate in your study* (Miro, personal communication, February 20, 2011); *I would be delighted to participate* (Meg, personal communication, March 15, 2011)).

As all my immediate respondents were male, I faced my second challenge of obtaining female participants. Coincidentally, a computer magazine editor, who overheard my first pilot interview, which was conducted in a café, enthusiastically offered to connect me with potential female participants via an email blast, from which I eventually obtained one of my female study participants.

My final challenge in obtaining participants was to validate their vocation as computer scientists and their avocation as classical music players. Often, due to either miscommunication or misconceptions, I was referred to near misses, like jazz players, or to financial systems analysts who were mistakenly considered to be computer scientists by their acquaintances. This entailed careful screening of responsive participants by interacting with them over the phone, and reviewing their biographical data.

The individual research participants will be introduced in more detail through their respective stories in chapter four, the Data (Stories) chapter.

2. Data Collection Methods

This section describes the specific procedures for collecting data, focusing on aspects of the conducted interview, additional types of collected data, validation of the data collection methods, and the data recording procedures.

a. Interviews

As outlined by Creswell (2003), the general knowledge framework adopted for research (e.g., social constructivism) along with the selected research strategy (e.g., phenomenology) guide the more specific data collection and analysis procedures. As such, a phenomenological case study, like the one pursued in this study, typically takes the form of interactive, open-ended, in-depth interviews in which the participants can talk openly about a topic without the use of overly restrictive questions (Moustakas, 1994; Creswell, 1998).

I conducted interviews in English, lasting approximately two to two-and-a-half hours with each participant, all face-to-face, except for one over-the-phone interview (due to geographical distance).

I derived the interview questions (presented in the Appendix) from the research questions identified in the introductory chapter of this document. They can be grouped into several high-level, conceptual categories: general family and educational background; early music exposure; other interests in youth; role of music-making in life; education and work experiences in computer science; managing involvement in the two disciplines of music-making and computer science; music-making informing thinking of computer-science work; computer-science work informing music-making; career decisions and conflicts; learning experiences and mentors in music; learning experiences and mentors in computer science; music practice traditions; hypothetical situations; and the emotional aspects of involvement within the two disciplines.

The conceptual flow of the interview, starting with general background questions and factual knowledge to gradually more abstract questions, is intended to provide interviewees with a warm-up period prior to the more reflective and focused questions on the relations between the two disciplines that may require more careful articulation. In addition, in order to keep the flow of the interview and guide the interviewees on the intended meaning of the question at hand, I have prepared a list of sub-questions associated with each question, to be asked if necessary. For example, the question *how did you manage engaging in music in addition to your work load?* could have been rephrased with the following two sub-questions: *Discuss occasions when playing your instrument made/makes your daily life hard?* and *What about occasions when playing made/makes your daily life easy?*

Recognizing that "good interview questions" are the key to my study, I took my interview questions on the road to try out various strategies for drawing out rich and full experiences from the interviewees. I first presented my preliminary interview questions to some acquaintances and other reviewers, and also conducted, as Glesne (1999) suggested, a pilot study (see Pilot Study section in this chapter). I then incorporated their ideas and reflections into the final version of my interview questions. Throughout this test period, I was aware of the need to formulate "good" questions (Glesne, 1999) by avoiding yes/no questions,[46] multiple questions,[47] leading questions, leading questions that may disclose the desirable response, and by incorporating "native" questions of common events. Moreover, I was also aware that in a phenomenological study I had to design questions that inspired the interviewees to spontaneously recall and reflect on their experiences. Lastly, I introduced triangulation (Creswell, 2003) into the interview questions, attempting to address similar issues through various ways of asking.

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[46] Yes/no questions were included only when the follow-up question was conditioned upon the response to the yes/no question.

[47] Multiple questions were included only when the initial question was a yes/no question.

b. Artifacts and Audiovisual Data

I collected several personal artifacts related to the participants, including photos, performance announcements, CDs, online recordings of music performance, announcements and descriptions of computer products and books written by participants, and incorporated some of these within the Data (Stories) chapter as visuals, receiving permission from the study participants to do so. I also collected email communication between the participants and me, as well as notes I scribbled during my interviews with them. These non-verbal modes of meaning may enhance and complement the reading of this language-centered document.

While I did not use the above artifacts as part of the thematic analysis, they helped me ground and concretize objects and events referenced by the participants throughout their narratives (e.g., listening to music performed by study participants and referenced in their narratives). Inclusion of multimodal actions as part of constructing meaning has been practiced by some researchers. For example, Heller (1997), in her ethnographic study, observed and captured multimodal actions carried out by the Women of the Tenderloin writing workshop she studied, to explore the association between sorrow and humor. For example, she incorporated observations of laughter and sounds like “chuckles” and “cracks” in her analysis of the manner these women tell stories that explore tragic aspects of their lives, combining emotions of anger, with seriousness and humor. Luttrell (2003) employs multimodal methodologies when bringing out the voices of pregnant teens, combining story telling with drawing, collage-making and role-playing, as the teens often preferred to “show” rather than “tell” (p. 148). Archer & Akert (1977) showed that nonverbal communication may contribute even more to the interpretation of communicative acts than verbal information, as the nonverbal aspects of communication are usually assumed to be under less conscious control by the speaker than the verbal content, and therefore perceived to be more reliable. Although out of the scope of this present study, it will be valuable to consider extensions to this study, in which aspects of the performed music, such as the genre, type of instrument, or the venue are integrated as part of the constructed meaning of music-making in the lives of these study participants.

c. Data Recording Procedures

Prior to the interviews, I captured via email basic biographical data (contact info, education, and work experience) about the participants, and information about the setting of the planned interview (e.g., date, time, and location).

During the interview, which was conducted at the interviewee's home, interviewee's workplace, or at my home (with an exception of the first pilot interview, conducted at a café), I used a digital audio recorder from where I transferred the spoken interview to corresponding digital files on my computer, organized as one folder per participant.

One of my main impressions was that participants were enthusiastic and grateful for the opportunity to tell their stories, often exceeding the assigned time period for the interview, making it challenging for me to stick to the time limit assigned for responses. In particular, participants often became excessively engaged with responses to the initial questions regarding family background and their music and work experiences, leaving less time for the other more reflective questions. In future studies, I could consider managing this issue by politely interjecting time-limit comments, politely moving to the next question, and possibly creating more focused background questions.

Another impression was that occasionally participants had difficulty recalling or articulating responses, especially to questions prompting their reflections and interpretations (e.g., questions on borrowing concepts/ideas from computer-science professional activities to their music-making activities) rather than soliciting factual data. Although I prepared myself ahead of time for this possible situation, I occasionally found myself on the verge of becoming disappointed during the interview, continuously considering the modification of questions, or even soliciting additional interviewees. I soon came to terms with this type of complexity in my study, realizing its likely presence in other groups of potential participants. In future studies, though, I may introduce a priori preparation for such deeply reflective questions.

C. Data Analysis Methods

As recommended by Glesne (1999), I began my data analysis during the data collection phase by reflecting on the interviews, using written notes. As soon as spoken data from the interviews was collected and transferred from the digital recorder to the computer, it was transcribed[48] applying Gee's (1999) concept of lines/stanzas to the written text, making it convenient for thematic analysis.[49] The line/stanza division, also applied in Mishler's craft-artists narratives of identity, *Storylines* (2004), is based on punctuation, syntactic/semantic structures within a sentence, paragraph annotation, and focus shifts within paragraphs. This preparatory massage of the interview data into discrete phrase-by-phrase language structures facilitated my subsequent thematic and linguistic analysis. Although all interview data was transcribed using this phrase-by-phrase stanza organization, the textual references made in the Thematic Analysis chapter to fragments from the narrative transcriptions are presented as continuous text, for space

[48] With the assistance of a transcriber.

[49] Part of the analysis methods in qualitative research, and used for examining themes within data.

considerations. The following is a stanza[50] example from Ernie's narrative (Ernie, personal communication, February 16, 2011):

so in seventh grade,
um, that's when I started,
ah, playing in band,
and I was playing in, you know, the last, last seat–
you know they have first, second, and third clarinet, right (laughs)
so I was third clarinet.

Following the representation of the spoken data in the stanza format, I began my three-step data analysis process, based on Creswell's (1998) data analysis procedures:

1) Conceptual analysis per participant (drawing phrases that represent concepts and ideas).
2) Creation of the participant's story (absent from Creswell's procedures and performed simultaneously with the first step).
3) Thematic Analysis across participants:
   - Grouping concepts and ideas into "meaning units;"
   - Reflecting upon and interpreting "meaning units;"
   - Constructing overall description of the meaning and essence of the phenomenon.

First, for each participant, facilitated by the stanza-based format, I began to extract phrases and paragraphs that represented some instances of seed ideas and concepts. For example, the concept of *participation and performing in musical groups* was initially extracted from the above stanza in Ernie's narrative.

As there were additional instances in Ernie's narrative of similar events of participating in an orchestra, I extracted them as well (Ernie, personal communication, February 16, 2011):

[50] During the data transcription into stanzas, I also occasionally introduced grammatical corrections, especially for the data collected from the native Israeli participant.

I also got into GBYSO,
the Greater Boston Youth Symphony Orchestra.
…
they um, so I was there for two years,
ah, junior year and senior year in high school
…
they, they, it's nice cause they rotate around, they switch,
so everyone gets to do different things.
but there was a … I remember for the symphony hall concert,
which we did when I was a senior,
we did Shostakovich 5th Symphony
and I was playing principle clarinet for that,
which was a, you know,
a very memorable experience.

Thus, as a result of its multiple instantiations in Ernie's narrative, the concept of participating and performing in musical groups began to form, becoming one of the salient concepts in Ernie's narrative. Similarly, other concepts formed, such as: playing in childhood with Lego blocks, inspired as child by clarinetist role models in the orchestra, worked on computerized music applications in college, appreciates both individual and team work, likes the social aspect of playing in musical groups, "being in the zone" while performing music, etc.

Simultaneously, with the extraction of concepts and ideas per participant, I began the creation of the life story of the participant from the transcribed narrative, transforming the narrative into a cohesive and condensed story. In addition to serving as a placeholder for attaching and expanding on ideas, the story facilitated my familiarity with the participant, and enables future readers to get acquainted with the participants prior to the thematic analysis without having to read their full narrative.

Finally, as more concepts and seed ideas emerged from additional narratives and as more stories were created, concepts became more involved and structured, leading the way to themes and subthemes with associated mini-narratives that grounded these themes. For example, the concept of participating and performing in musical groups recurred in multiple stories with varied manifestations such as inspired by other players, social world, visibility, sense of gratification, and facilitating work skills. The concept of social world recurred further with various manifestations such as creation, preservation and renewal of friendships, sense of belonging and boosting of self image, and connecting with the "other" that is different from work colleagues. Similarly, additional themes emerged, such as abandoning music-making as a profession and returning to it later in life as an avocation, use of visual thinking at work and while playing music, etc.

Sociolinguistic analysis, which I occasionally applied to narrative fragments, often helped me refine emergent themes or discover new themes. For example, the pronouns *I* and *you* that participants used interchangeably provided me with cues as to the level of personal involvement or degree of agency participants convey with respect to an action, versus distance and passiveness in their actions. In addition, I observed through the language they used how they attributed either blame or praise to other characters in their lives, such as family members.

D. Presentation of Data and Thematic Analysis

While research involves three equally important activities of discovery, interpretation and presentation of knowledge, the majority of social science researchers have undervalued the importance of strategies and methods used in the final stage of presenting their findings in a manner that is comprehensible and intriguing to their audience. In addition to the writing guidelines of form and style outlined by Glesne (1999), I paid attention to the following aspects of presentation of knowledge during the writing of the participants' life stories and the thematic analysis:

- Handling of emotion-overload in characterization of participants;
- Making sense out of data: linking small details to universal themes;
- Interweaving thematic analysis with research theories;
- Handling of excessive interpretation in thematic analysis.

First, our natural tendencies as human beings encourage the overload of emotions (i.e., sentimentality) in our writing, especially within character description. When a writer overloads a character with emotions, the location of feelings is actually not inside the character as it is when the writer uses sentiment, but is rather with the writer (i.e., his bias). As such, readers are likely to sense that these emotions are pushed artificially and therefore may not trust the writing or not take it seriously. Their reaction may then interfere with the main issues the writer tries to raise.

With characterization being a valuable ingredient in my study of rendering people, I resisted excessive sentimentality and the creation of heroes, while simultaneously creating their complexity by applying the saints/heroes guidelines (Heller, 2006a; 2006b) to slightly lower them from their pedestal: When rendering a person or situation attempt to provide just the facts; and when rendering a hero/saint, describe these moments where your hero is "goofing" a bit, as George Orwell did in his essay "Shooting an Elephant" (Orwell, 1984). Orwell established himself as a trustworthy narrator by taking himself off the pedestal right at the beginning of his story: "I was hated by large numbers of people–the only time in my life that I have been important enough for this to happen to me" (p. 35). Throughout the writing of my study, I remembered Primo Levi (1995), a master of characterization, whose language choices when describing horrific Holocaust events offer precision (he is a scientist), no indulgence in feelings and suspense of judgment. Translated to language specifics in this study, I refrained from using praising adjectives like *wonderful*, or intensifiers like *very* or *highly*, even when characterizing unique cognitive abilities of participants such as Ethan's ability to "dial up" music compositions from memory when feeling like playing his instrument.

Second, I paid oath to my data, by linking seemingly small and insignificant details to a larger universe of meaning, similar to using a focus/wide angle. In "Optilenz," for example, Heller (2002) uses the Optilenz machine that assists her aging father in reading to evoke the meaning of getting older and the difficulties it entails. Similarly, I linked the Lego blocks in Ernie's childhood to his analytical tendencies, Ethan's slide rule to the more universal meaning of empowerment in math, and the record player in Miro's early life to his combined musical and mechanical tendencies.

Third, I have provided my interpretations and theories of the data and woven them into interpretations and theories provided by other researchers, as seamlessly as possible. Additionally, for continuity, all quotes from study participants (including the pilot participants) are represented in italics, and all quotes within this dissertation that are 40 words or more have not been set off in block quote formation[51] for the sake of maintaining the overall flow of the narrative.

Finally, to reduce the occurrences of over- or mis- interpretation of data, and not to be overly definitive or committed to my discovered interpretations, I described some of my discovered interpretations with qualifier words like *possibly* and *likely*.

E. Pilot Study

In order to confirm the validity of the design of my study as well as to be informed of potential limitations of various aspects in the design, I have conducted a pilot study with two participants, prior to my actual research study, as suggested by Glesne (1999). I utilized the

[51] An American Psychological Association (APA) formatting convention.

pilot's findings to learn about the recruitment process of participants, logistics regarding interview location and recording equipment, validation of interview questions, and mostly for getting a glimpse into emerging ideas and themes.

The rest of this section describes my findings in the pilot study in more detail, expanding especially on the emergence of potential themes.

1. Pilot Participants

As previously mentioned in the Data Collection Methods section, throughout preparation for recruiting pilot participants, I became aware of the following findings:

- There is no likely shortage of willing and matching participants for the real study;
- The word-of-mouth profile specification I used for describing the qualifications of potential recruits required additional screening and reviewed biographical data;
- Pilot participants were enthusiastic about participating in the study.

2. Logistics of Interview Location and Recording Equipment

Although prior to the pilot study, I considered interview logistics issues as insignificant, especially relative to the importance of validating my interview questions, it proved to be otherwise. The first pilot interview, conducted in a Café in the morning hours upon the interviewee's preference, stalled as the place was booming with customers, and therefore noisy and scarce in electric outlets. For subsequent interviews, I insisted on a home environment, either at the interviewee's home or at mine. During that first pilot interview with David, I found my recording equipment, a portable Sony Mini Disc digital recorder, impractical for recording interviews. Although I have used it in the past, I found its interface for pausing and resuming a recording to be unfriendly, and the potential of losing my recorded material too risky. Moreover, the transfer of recordings to the computer was not straightforward, and was achieved only with a lot of hardship. With the help of David, the first pilot study interviewee and an expert on recording equipment, I purchased a sophisticated, easy to use, Zoom H2 Handy Portable Stereo Recorder, with which I successfully accomplished all my interviews.

3. Validation of Interview Questions

Recognizing that good interview questions are the key to my study (Glesne, 1999), I observed the reactions and responses of pilot interviewees during the pilot interview and obtained their reflections on some of the questions, eventually producing my final list of interview questions. Below is a representative list of modifications introduced to the original interview questions as a result of this reflective process.

- As participants sometimes exhibited difficulty to respond to a question, I composed follow-up sub-questions that could help trigger a response to the top level question, if needed. For example, the question *How did you start your musical life?* had the optional follow-up question *What instruments did you play?*
- With pilot participants occasionally overextending their response beyond its allocated time, I trained myself to politely interject a time limit comment or politely move to the next question.
- Direct feedback from David, the first pilot participant, and my observation of the compounded question asking to reflect on what Einstein told Suzuki (1969, p. 90), the pioneer musical educator, motivated me to eliminate that question (*Einstein said that*

his own relativity theory ". . . occurred to me by intuition. And music is the driving force behind this intuition. My parents had me study the violin from the time I was six. My new discovery is the result of musical perception." What is your thinking of the phenomenon Einstein describes here? Have you had a similar experience? Can you talk about it?)

- Reviewers suggested questions that I neglected to ask while they considered them useful, such as *Did you ever consider a professional career in music? If so, why did you not choose that path?*
- Reviewers recommended that I add the symmetric reverse of the given question *Has music-making informed or affected your computer-science or engineering skill set? If so, in what ways? can you give specific examples* (i.e., *Have you found that your computer-science or engineering skill set has enhanced your music-making? If so, in what ways? Can you give specific examples?*).
- The above two symmetric questions regarding bi-directional informing between the disciplines of computer science and music were of special concern to me, as to the ability of participants to articulate their experiences and thoughts. However, reviewers of these questions believed that interviewees should be able to articulate such connections, at least indirectly and hopefully directly, and that the best answers are often the spontaneous ones.

As demonstrated by David and Martin, the two pilot study participants, David was verbose and articulate in his response to these questions, while Martin was more hesitant. From my discussions with David, I learned that a similar situation may be reflected in the real study as well, as participants may not be able to recall or articulate their experiences.

4. Getting a Glimpse into Emerging Ideas and Themes

In this section, I summarize the main ideas that are salient in the narratives of the pilot participants, David and Martin. These ideas provided me with an insight into the potential themes that were likely to come up in the narratives of the participants of the real study. For each of the pilot participants, I first present a short biographical summary, followed by the list of representative ideas. For the sake of reading continuity (i.e., flow of the story and analysis) throughout the thesis, quotes are incorporated into the sentences via italic notation. As shown in the upcoming Thematic Analysis chapter, numerous ideas identified in the pilot analysis are repeated through the analysis of the real study.

a. David: Major Narrative Ideas

David, in his early 60s, is a computer scientist and baritone (and euphonium) player, with childhood experience in piano, cello and percussion. Born in Michigan into a musical family and raised in central California, he now lives in the Boston area. After graduating from UC Berkeley with a degree in computer science, David embarked on a 27-year, high-tech career starting as a programmer with McDonald Douglas for over two years, and continuing in technical marketing and sales positions at Digital Equipment Corporation[52] (DEC) for over twenty years. When DEC's new, unsuccessful line of computers was built, David began working in several startup companies, including Chipcom[53] as a product marketing manager, and Prominet[54] as a VP of product marketing. David was traveling all over the world, spending sometimes 40 weeks out of 52 on the road, until it became too stressful, and

[52] Digital Equipment Corporation (DEC) was a major American company in the computer industry and a leading vendor of computer systems, software, and peripherals from the 1960s to the 1990s.

[53] Chipcom was an early pioneer company in the Ethernet hub industry.

[54] Prominet was an Ethernet switch router pioneer company.

eventually in the year 2000 David suffered from some health issues, which he recovered from. At that point, he realized that he was done working at this intense mode and began teaching math at his local high school for five years. During his high-tech years and while teaching, David continued to play in a variety of amateur and professional ensembles including the Long Beach State University Wind Ensemble, New England Wind Symphony, the John Leite Concert Winds and various community bands. Over the last five years, David has been a student of a local tuba performer. He is first baritone with the New England Brass Band and solo euphonium with the New England Wind Symphony (see Figure 1).

Figure 1: David playing the euphonium.

The following are the main ideas that came up in David's narrative during our personal communication on January 14, 2011 at his home in Western Massachusetts.

1) Raised in a musical family. David's parents were both music majors. His father, a clarinet and saxophone player, was a high school band director. His mother, a violinist and violist, was a public school music teacher and later on became a curriculum developer.

2) Played multiple instruments. David started his musical life with the piano. Quitting after two years, in fifth grade, he took on the baritone, his real love. He also picked up the cello in

his childhood but quit after three years. For a while during high school, David was also a drummer.

3) <u>Participated in musical groups.</u> At a young age David was exposed to musical groups through music camps his parents attended, listening to known musicians like Bill Bell from the John Philip Souza band and New York Philharmonic, and Arnold Jacobs from the Chicago Symphony Orchestra. He then joined his schools' and state's bands/orchestras. As a busy professional, David played with various musical groups when time permitted *(I was playing in this professional wind ensemble but I, during this period I was really career driven… music was a relaxation for me… I would go six months between picking up the instrument and then someone calling me and asking me to play this or do this).*

4) <u>Performance with musical groups makes David feel physical sensations and in total focus.</u> The most rewarding performance for David is with musical groups. During these times he is elated and feels shivering in his body *(my feet didn't touch the ground for days… even now it sends shivers down my spine)* as well as totally focused and in the zone *(by the time we got to playing that march, the whole group was just like, totally in the zone… you get into performances where the music and the kind of the 'everybody playing together well musically' together transcends thinking about it)*.

5) <u>Social aspect of playing in musical group.</u> David believes that a musical group outlet is useful for software programmers, as they often lack interpersonal skills *(this gets into my software engineering mentality that very often their verbal communication skills aren't very good and their interpersonal skills aren't very good, but they can communicate musically).*

6) <u>Musical group experience informs motivation</u>. David's first band experience was intimidating, motivating him to improve *(I was awful. I couldn't play anything… it was a*

band with high school kids mostly and I'm just out of the fourth grade). With the conductor's positive reinforcement, he became first chair in school and camp bands upon entering junior high.

7) Musical environment. David believes that some of the best music programs in the country were in the Midwest, where he grew up.

8) Parental involvement. David's parents, especially his mother, were quite forceful towards their children with respect to music practice, negatively affecting his older brother's mental health. Watching his brother's mental health deteriorate, David became assertive about quitting the cello and continuing only with his baritone *(don't push me quite so hard, let me figure it out on my own).* Although pushy, David's mom was musical and impacted his musicianship by providing him useful feedback (*my mother impacted my musicianship more than anyone).*

9) Primary childhood interests: building with mechanical things and reading. With his father, whose family was in the automotive industry, David used to take apart and rebuild cars *(I just loved mechanical things, always loved them, still do… I remember seeing all these engine parts and watching him… he would say "well, go get this screwdriver, and go get that). So I would just help him a little bit).* He also loved reading, especially science fiction *(read tremendous amount um and way ahead of my age).*

10) Did well in algebra and loved the sciences. Although initially frustrated with arithmetic in childhood, David did well in Algebra starting in junior high *(not that I liked it, but that I was good at it)* and loved physics.

11) Music teachers. David looked up to his first and only private baritone teacher, with whom he studied throughout high school. He also enjoyed his school's band directors, including his

junior high band director *(who got you to enjoy playing in the ensemble),* high school band director *(a very strong figure in my development as a high school musician)*, and the musically demanding director of the Eastman Wind Ensemble who was capable of getting out the emotions in players without intimidating them (*he would just get you through the love of music).* Although not directly affected, David recalls another high school band director, renowned for his tyranny (*put kids on the spot, he would have kids crying after rehearsal all the time… I wasn't fearful… because I could always play the part and be strong enough to do that).*

12) Career conflicts. David wanted to be a musician and knew he could become one if he set his mind to it. However, he gradually converged on a computer-science career, calculating that he cannot make a living from music *(there aren't that many options for somebody that plays this instrument),* preferring to connect with music as an optional outlet with no career-like implications *(I always wanted it to be there for me but I didn't want it to be the thing that my life was based on).* Living with professional musician parents and exposed to known musicians, David became aware of the likelihood and level of commitment required to become a successful, professional musician.

13) Mechanical background informed work with computers. David's passion for building with mechanical objects is reflected in his later engagement with forensic activity of computer operating systems *(much related to that kind of… a new type of mechanical thing, and I can figure out what makes them tick, what makes them work, and how to make them run faster*). As with cars, David would get into the internals of the operating system, fix bugs, and recover customers' disk drives.

14) Rhythmic knowledge in music informed knowledge of fractions in math. David felt his knowledge of music rhythm assisted him in arithmetic *(in junior high I realized, that I actually was pretty good at some things… you can do this measurement and then do half of it, and start to work with fractions, and this is really coming from fractions in music*).

15) Music informed listening skills at work. David believes that his music listening skills nourished his fine listening skills when listening to customers *(it's like improvisation… I was very aware of, my ability to perform, and sell, and use your communication skills the same way you do it with you … do with music).* With his listening ability, he felt it was natural for him to become a sales person *(picking up on what they were trying to accomplish, listening to them, and then being able to say the right things to explain the technology).* These skills also informed his listening skills as a math teacher.

16) Ability to focus in music informed ability to focus at work. David can train himself to focus at work like he has been focusing during his music performances *(when you're in the zone in music and you're really performing, and you're just completely focused and nothing's gonna distract you, and you're just so aware of what's going on in this one thing, and completely unaware of what's happening in anything else. And that was a skill that I applied in business).*

17) Music informed sensitivity at work. David thinks of himself as sensitive to his customer needs, adjusting his technical sales presentations depending on the type of audience, technical or managerial. David applied his sensitivity also as a math teacher, reading students' gestures as possible signs of their coping with math understating *(I would tell the kids that one day I would look at your eyes, your faces, and if, you know, and try to read them and try to understand where you are, cause part of it would be looking for kids that*

were, you know, emotionally bothered with things going on in their lives, but part of it is being able to understand what I'm doing … that they understand the math). David believes his sensitivity was informed by his music skills *(it's no different than that sensitivity that you have of interpreting what the conductor's trying to tell you with his body, and his hands, in an ensemble, in a performance).*

18) <u>Ability to focus in music carried to work</u>. David is aware of the influence of his ability to focus in music on his programming and business skills *(I was extraordinarily aware of this. I have this extraordinary ability to focus and really understand things and really just dig deep. And that was a skill that begun in music, and something I learned to apply pretty much when I was in college, to non-musical things… when I had to do the computer programming and the studying and writing papers).*

19) <u>Holistic as well as detailed analytical thinking ability in both music and work</u>. David has the ability to adjust his focusing level while thinking, zooming in and out. He can either look at things at a high level being sensitive and emphatic *(the ability to be aware of your surroundings… and react and kind of be inclusive… kind of social skills),* or at a low level, focused and in detail, like when working on the mechanical projects with his father. David believes that his ability to focus, which is the analytical ability that many engineers own, is likely to be the left part of his brain *(that notion of precision and detail, and things that are important as we do engineering work… really understanding how things work… that's the analytic side),* while the empathic ability to see the whole is more the right side of his brain *(then there's the emotional side, ahh I'm making music, it's just gorgeous, I love this).*

David feels that he thinks holistically as well as in a detailed, focused mode when making music and also at work *(I have strong communication skills but on the other hand I have the ability to go toe-to-toe with engineers right down to the nits-and-grits).*

20) Music performance skills instill empowerment at work. David's music performing skills empowered him with the ability to confidently and fearlessly deliver presentations at work in front of a large audience, making him also a successful marketing and sales person *(I was very, very aware of integrating my musical, performing skills with my technology skills… I really was one of the best in the industry at explaining technology… being able to present it, being able to sell it, being able to uh, understand from a customer's description of what their problem, business issues were).* His stage presence, whether performing with a musical group or delivering technical and sales presentations always empowers him *(I'm on stage, now I perform. When you stand in front of an audience you have control and I like that*).

21) Thinking with patterns in both music and work. David was heavily thinking with patterns while analyzing performance of computer systems from a set of graphs *(you get used to looking at those patterns*) and also while performing statistical analysis *(you want to come up with a hypothesis of what's going on, and then use statistics to see if it could be true. But you have to have some sense that there's a pattern in here somewhere, I mean you can't start from drowning in emotion and utter chaos).* David also taught his math students to be sensitive to patterns when looking at graphs. Similarly, in music, David thinks that part of creating music comes from obtaining relationships between notes *(if you want to make music you can't just look at the notes, you've got to see the relationships in the notes).*

22) Thinking visually in music and at work. While running computer performance benchmarks, David can visualize how the information flows inside computers and computer networks *(I had*

this ability to visualize what was going on inside the computer, you know I understood how data flowed inside the computer, what parts of the computer worked well and which parts you wanted to avoid). David has a similar visual ability in music *(if you have a melody and the melody goes between different instruments in an ensemble, and it's mixed with the harmony… you can see a line flowing through music… "it's almost like you can see the black notes on the page, and, and so I was aware there was some relationship between that, and, and um this sense that I had, knowing how to visualize computing systems).*

23) Bringing music together with academia and work. While at UC Berkeley, David elected to take as many music courses that could be authorized as part of his computer-science major, including participating in their brass quintet and wind ensemble. In addition, prior to his work presentation in front of 4,000 people, David spontaneously performed on a rented trumpet *(I said, "oh I've got to wake them up." I started my presentation behind a screen with a spotlight with me doing this, and playing When the Saints Come Marching In, and then I came out on the stage with my computer and my digital technology… explaining how voice and data were going to get integrated).*

24) Music is enjoyable during retirement. Starting his retirement, David wanted to get back to the same, high level of baritone performance he had before. Although he did not plan his retirement around music, now that he is retired, music is the thing that he spends most of his time on, participating in musical groups, summer music camps for adults, and resuming lessons with a private baritone teacher.

b. Martin: Major Narrative Ideas

Martin, a computer scientist and a pianist, was born in Montevideo, Uruguay, where he was raised and educated, receiving an Electrical Engineering degree from the University of Uruguay (see Figure 2). At age six he started piano lessons with his uncle, a cellist, who instilled the love of music in his soul. Admitted to the National Conservatory of Music at age 14, he quit after a few years due to the academic demands of his high school. He immigrated to the US in 1957. After a stint at MIT, where he received a graduate degree, he started working for Bolt, Beranek and Newman[55] (BBN) as a computer scientist until his retirement in 1995. At BBN he worked on the library of the 21st-century project, devised techniques for encoding encrypted information, created sound signals to reproduce a sonic boom, evaluated effects of sonic booms on the environment, worked on experimental psychology projects, wrote papers, and participated in conferences. While in the US, he resumed his piano playing, studying with Lenore Engdahl of Boston University (BU). Presently, Martin continues to play and offers occasional music soirees at his home, both in Lexington, Mass., and in his native Uruguay where he spends the northern winter.

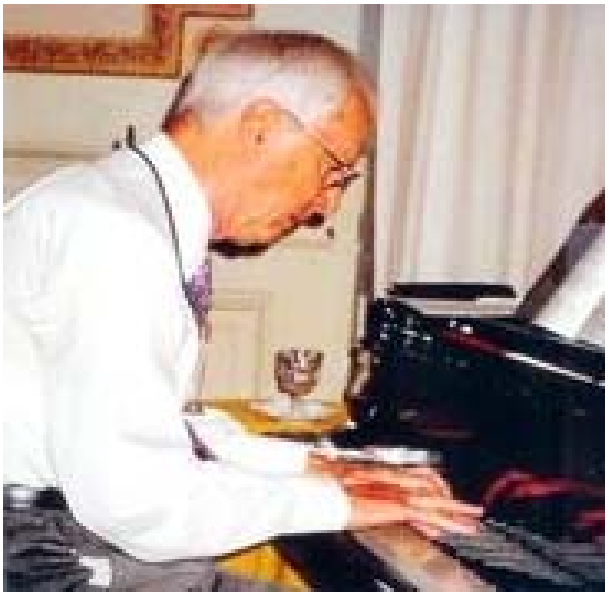

Figure 2: Martin performs in a piano recital (Salon Dorado, Hotel Argentino, Piriapolis, Uruguay, 2005).

[55] BBN Technologies, formerly Bolt, Beranek and Newman, is a technology company in Cambridge, Massachusetts, best known for its work on packet switching technology and its construction of the Interface Message Processor–the first router.

The following are the major ideas in Martin's narrative, gathered during our personal communication on January 17, 2011, at his home in a suburb of Boston.

1) High quality education in math and sciences in elementary and high school. Martin practiced experience-based education in elementary school *(we would go and make observations)* and went through a rigorous mathematical environment in high school *(in Uruguay… mathematics was foremost).* His high school math teachers were known mathematicians who published papers.

2) Parents had limited musical education. Apart from being opera addicts, his parents were not musically educated. However, his mother would make him practice *(my mother was a taskmaster)*, had a keen ear, and criticized Martin's playing *(she would hear every mistake, but I hated to have her around when I was playing, because she would… make faces).* His father, an accountant, did not have a good ear and sang out of tune.

3) Studied piano with his admired, cellist uncle. Martin adored his uncle, a Montevideo's Symphony Orchestra cellist, composer, and a co-owner of a radio station that introduced young classical musicians *(my uncle was a real father figure in my life).* Martin's uncle coached both Martin and his own son *(he had a gift for melody and harmonization… we learned the love of music… those lessons were so dear to me),* and even dedicated a waltz he composed, *Gentile Tempiero (a nice thought),* for Martin's tenth birthday.

4) Primary childhood interests: building with mechanical things and astronomy. Martin loved to take things apart, especially in his childhood playing with construction sets that his father bought him, such as the Meccano and Märklin construction sets. Through a collection of books that his father bought him, Martin also became fascinated with astronomy. His early passion for astronomy persisted later through performing routine observations of the moon

and stars, building his own telescope with his construction sets, convincing his father to buy him a lens to see the moon, and attending Cosmography classes.

5) Fascination with high fidelity. Fixated on high-quality music system *(I wanted to hear good music),* Martin researched American magazines on its design and parts and found someone to build such a system. He financed this project with his first job as an assistant actuary in a bank.

6) Becoming an engineer. Despite his parents' wish for him to become an actuary, Martin insisted on becoming an engineer *(and I was "No, I want to become an engineer").* As soon as Martin finished his engineering degree, he was hired by a Uruguayan airline, and spent several months training in Washington, D.C. with an experienced pilot on aspects of airplane maintenance.

7) Exposure to music performances. Through his cellist uncle, Martin had access to the orchestra's rehearsals *(that was the golden age of the orchestra),* and also attended numerous recitals and concerts of known pianists like Arthur Rubinstein (1887-1982) and Maria Tipo (contemporary).

8) Participating in musical groups. In 2001, Martin joined the newly formed BPAA, participating in their soirees and competitions. He enjoyed both its social aspect *(it's a very, very nice group… not all professionals, but there are a lot of doctors and a lot of computer scientists)* and its musical aspect *(all kinds of abilities).* He even reached the semifinalist level at their international competition shortly after he joined *(it is unbelievable… these people could have gone into a career).*

9) Aesthetic pleasure in music and at work. Music informed Martin's aesthetic thinking in computers *(although I have to say I am much more sensitive to music… the emotional*

response to music is overwhelming sometimes). Martin physically senses his aesthetic pleasure from music through physical sensations while listening, as happened during a Sergiu Celibidache (1912-1996) concert with the Munich Philharmonic Orchestra *(I could see the arch, the violins moving, I could hear it, and all of a sudden the music started coming up, and all of a sudden the music, and I realized this was a miracle, it was, I was, I stood in awe, I will never forget that moment… the birth of the musical of silence).* Martin also experiences some aesthetic pleasure with his computer-science work, although not as intense as in music. This occurred when he was working with the Fast Fourier Transformation[56] (FFT) and was able to discover some higher frequencies that cannot be picked up by the sampling rate *(I was able to see them, oh my god look at that… I remember that was an aha! moment).*

10) <u>Bringing music together with computer science</u>. First, Martin met another piano player at BBN, who was trying to make a computer play music *(he was intent to play Chopin in tune).* Inspired, Martin tried to get other BBNers interested in building a system that could produce music and even wrote a pre-proposal, but the project eventually fell between the cracks *(there is indeed… an algorithm… for waltzes or something like that… you can select a theme at random, and then you repeat it and revolve it in a certain way).* Second, while at BBN, Martin began thinking about the parallels between music and mathematics *(Why is music so beautiful? How is math so beautiful, so attractive, so aesthetically pleasing?).* Third, Martin and some of his colleagues were also proactive in having BBN purchase a piano *(we decided, it would be nice if there was a piano there so people who come can have their lunch, read, and have some music in the background… I got to be known at the time as the guy who played the piano).* Lastly, BBN organized musical nights, as many people played musical instruments and also sang.

[56] An algorithm to compute the Discrete Fourier Transformation (DFT).

11) Making music is never completely satisfying. Music-making is hard and almost never satisfying *(it is so difficult to produce music at the level that you want it to be, at the level that you admire in others).* For example, when Martin finished his BPAA competition performance, although people applauded and congratulated him, he felt he did not play well *(they were crazy, I just dropped notes everywhere, I knew how I played, you know I was nervous like hell… I didn't play that well at all, but they thought otherwise).* This reminds Martin of known pianist Michelangeli (1920-1995), who due to his obsessive perfectionism, often considered concerts ungrateful and would not enjoy his own recitals, missing some of his own scheduled concerts.

12) Visual thinking in computer science. Similar to mathematician, Benoit Mandelbrot (1924-2010), who talks in his book about how he visualizes the shape of an equation in space *(and when he has that… then he can solve it),* Martin visualized in one of his computer-science projects. When devising a text-compression algorithm based on Huffman's (1925-1999 encoding for the library project, he used a methodology of direct addressing using a series of jumping locations that had a visual character *(because I visualized that as being a cat, but I was very proud of that, that was one of my best early programs, very short routines).* Martin believes that this visualization helped him in designing that algorithm.

13) Music performances in retirement. Upon retiring, Martin extended his stays in Uruguay with his wife in a small beach town, receiving permission from one of the hotels with a good quality Yamaha piano to practice and perform *(I decided, I always wanted to say, "I do not want to end my life without giving some kind of a public recital,"… and I started giving recitals, in summer, you know, preparing in the winter and playing in the summer, it was fun).*

14) Piano playing alleviates Arthritis pain and also depression. Martin's doctor recommends that he resume playing the piano to alleviate his arthritis pain *(I'm beginning to feel the effects of, the effects of arthritis in the fingers, and my doctor told me the best thing you can do is play the piano).* Playing will also reduce Martin's stress that began with the financial loss he suffered as a result of the great recession.

15) Living without making music or without computer science is a significant loss. As Martin is getting older, he is living without making music, which is a big loss for him *(there isn't a day that passes where I say that I have to get back and I play sporadically, yesterday for example, I sat at the piano and played for a while).* Similarly, he would not be able to live without computer-science work *(I think it was an early vocation, and the right vocation*). If he could choose his career now, he would have chosen particle physics and cosmology. He regrets that he will not live to see the dark matter,[57] a topic on which he wrote a book *(when I retired, I decided to have something for my grandchildren,* and *I wrote a book called "The Forces of Nature").*

The following chapter familiarizes us with the study participants through their individual stories, highlighting salient concepts and ideas in each story in preparation for the thematic analysis in chapter five.

[57] Matter hypothesized to account for a large part of the total mass in the universe.

IV. Chapter Four: Data (Stories)

In this chapter I present the life stories for each of the seven study participants: Stan, Ernie, Ethan, Meg, Miro, Sol, and Delia. Each story, created directly from the participant's interview-based narrative, familiarizes its readers with the participant and facilitates understanding of the subsequent thematic analysis across participants. The quotations from each study participant are represented in italics and were pulled from our personal conversations, which took place on the dates listed below. Their stories are presented in the following order:

- Ernie: February 16, 2011;
- Stan: February 17, 2011;
- Delia: May 5, 2011;
- Sol: February 28, 2011;
- Miro: March 17, 2011;
- Meg: April 2, 2011;
- Ethan: February 21, 2011.

A. Ernie

Catching up to the local language and academics has occupied Ernie since he began to move back and forth between Israel and the US with his parents at the age of five. With help from his parents, his own persistence, and summer classes, Ernie ended up in the most advanced math class in high school. He also became the first clarinetist in his school band in 8th grade *(I remember looking at the first clarinet players, who were moving their fingers really fast and they can play all these high notes, and I thought, "wow that's very impressive, I wonder how they're doing all that?"...and by, I think by the end of eighth grade, I think I was playing first clarinet, already)*.

Ernie, now in his early 40s, was born in Israel to an Israeli father and to a daughter of Romanian Holocaust survivors. His parents met and married in Hadera, a northern beach town in Israel where Ernie spent his childhood, and to which he later returned to during summers and Jewish holidays and stayed with his grandmother. With both his parents pursuing graduate degrees in Chemistry, he moved to Oakridge, Tennessee for his father's post-doctorate at Oakridge National Labs. After two years and with the addition of Ernie's younger brother, they settled back in Israel, this time in its southern region, near his father's research and teaching site at the Institute of Desert Research. Then, after four years, in 1982, when Ernie was a 6th grader, they again moved to the US. As soon as they settled in Lexington, Massachusetts, his parents offered Ernie the opportunity to play a musical instrument, and he chose the clarinet, which caught his attention when watching an educational TV program that demonstrated sounds and shapes of musical instruments *(but for some reason the clarinet stuck in my head, I thought that was kind of neat. I don't know, I don't know why)*.

Back then, Ernie did not imagine that his love of building with Lego blocks would enable him to experience these mathematical and musical worlds as one. At five years old, he loved building with Legos, enjoying following the instructions and going through the pictures and the steps and eventually getting to the final result. At age seven, he built from mechanical Legos with gears and motors a big toy-car with an engine, a shifter, and a steering wheel.

This favorite childhood pastime reappeared at an important point in his life where he put computer science and music together as one discipline, creating a computer that recognizes music that is played by a piano-roll player made out of Legos *(I'd built this thing out of Legos where you'd stick the piano roll in this device and and set it up, and turn on the Lego motor and it would scroll, right? And then I had a video camera in front of it trained on this piano roll scrolling thing, um, and then the video camera went to a computer that I programmed to listen to–I mean to look at data and translate all the lines on the piano into MIDI,*[58] *and then MIDI got sent out to the Bosendorfer piano).* This project was a turning point for Ernie *(it really sent me off on a new trajectory, you know, it was a really pivotal changing point for me where I realized, "oh I can do computer programming and music together as one discipline," because up 'til then I had been doing computers and electrical engineering and I was doing music, and I was doing both of them and they were fun but they were separate, like non-parallel intersecting engagements, whereas here, they intersected, you know, I was, I was using skills from both and it was, it was really exciting).*

Orchestras and bands played an important role in Ernie's musical life as they brought him together with famous musicians, motivated him to be a better player, enabled him to rotate around various clarinet roles, and made him experience stage performance. The first time he

[58] MIDI (Musical Instrument Digital Interface) is an industry-standard protocol that enables computers and electronic musical instruments to communicate and synchronize with each other.

came together with the top players in Massachusetts was at a summer camp in Maine, after he made it to the Greater Boston Youth Symphony Orchestra (GBYSO[59]), although only as an alternate *(and that was, that was amazing because that was the first time I got to see all these players on a completely different level. You know, here I was playing in high school but then I saw all these–in GBYSO it's from all of Massachusetts, you know it's the top players in all of Massachusetts, so I got to see how amazing they were and I, I realized I had a long way to go).* He recalls a GBYSO performance at the Symphony Hall in Boston when he was a senior in high school, in which he played as principle clarinet Shostakovich's (1906-1975) Fifth Symphony *(which was a, you know, a very memorable experience).* Playing in one of the most famous concert halls in the world where world-famous players perform was a dream for Ernie *(here I am, sitting in one of the most amazing orchestra halls in the world, you know, just kind of playing some notes, it was really really amazing… I was just kind of warming up on stage, you know, I was thinking like, "wow look at this" you know, and then we played and it went really well and it was really good… ya it was totally thrilling, you know, you're sitting here, because you're think- you start thinking about all the amazing world class musicians who've been on this stage,* and *how they played,* and *Harold Wright was the principle clarinetist with the BSO at the time,* and *you know I was thinking, "wow he gets to play here all the time,"* you *know and you play some notes and it's just, you know it's amazing, you play one note and it just fills the hall, It's just, it's, it's completely gorgeous, It really is an amazing hall).*

Music took on a new meaning of achievement, early on in Ernie's life, as he always wanted to play the best he could *(there was, you know there was always a little bit–I don't want to call it competition–or um, but there was always looking to see other players playing and see how good they were or being inspired by that, so I don't know if I felt competitive or*

59 Now called BYSO (Boston Youth Symphony Orchestra).

just motivated by that, you know. But that was, I think it was always important to me to be playing as, you know, as best as possible). He even made his high school band director arrange for him to perform a clarinet concert the following year after hearing someone else do it. During his high school years, Ernie played solo parts and performed beautiful Klezmer clarinet parts *(so that was a really wonderful experience, I remember um, you know, getting assigned that and, and playing it and rehearsing it and it was just, just fabulous).*

Ernie also felt early on how gratifying it was to play the clarinet, and that feeling became valuable for him *(so, um, I think I've always, you know pretty much since starting I think I've always really enjoyed it and felt it was very gratifying and I've always wanted to improve and make myself better).*

Music was so important to Ernie that he chose to enroll at MIT partly because of its amazing music program, earning his B.A. in electrical engineering and computer science, with a minor in music, and then went on to get a master's degree. While at MIT, he continued taking private, weekly clarinet lessons at NEC with the head of the woodwind department. He also auditioned annually for an MIT music class that would grant him scholarship for his music lessons, but did not make it in the first year *(so I've never been too good at auditions, that's um, it hasn't–you know it's always been hard… getting rid of the nerves is very difficult… you have to convince yourself that you're confident, that you're able to do this).* Ernie's persistence to re-audition granted him a second audition, which awarded him the scholarship. Persistence has previously been demonstrated by his father when Ernie was rejected in the early admission process to MIT. His father did not give up, and helped Ernie reapply with extra supplemental material in regular admission *(maybe I got that from* *my dad, just this kind of persistence thing, you know you have to–you don't want to be too pushy–but … it's also important to kind of let people know if you care about something*).

Ernie's family was not particularly musical, apart from his brother who took piano lessons but never advanced and quit, and a great uncle on his mother's side who was a violinist in the Poland Symphony Orchestra. His parents almost never pushed him to play *(pretty much 90% self-motivated*). They were always helpful backing him up when he needed to be excused for not enough practice. Moreover, they supported his musical needs, driving him to lessons and orchestra sessions, paying for his lessons, and buying him good quality clarinets *(he talked to my parents and they said, "well we just bought these clarinets" and he's like, "ya well that's not going to work, he's going to need these other clarinets," so you know, so we returned the old clarinets, and I'm sure they had to, they lost some money on that, and we bought new clarinets with the new teacher, you know. So they were–he said we had to do it so that's what they did, so they were very supportive in terms of that)*. Ernie appreciated their supportive but non-pushy attitude, especially after learning that his violinist friend quit the violin as a result of his pushy mother, a piano teacher, demanding that he practice a lot *(I think she pushed him quite a lot, um you know I think she demanded he practice a lot, and, what happened with him was, you know, as soon as he finished high school he quit, you know, so I think there was, that might have been too much pushing, where as for me, you know, I still play today. So, I've been playing ever since).*

Ernie's first encounter with computers was during junior high school when his dad bought a new Apple II Plus computer. One could play games on it as well as program. Ernie was attracted to the programming aspect and together with his friend wrote programs in BASIC.[60]

[60] A computer programming language that emphasizes ease of use. Acronym of Beginner's All-purpose Symbolic Instruction Code.

His enthusiasm with his first Apple computer started his long journey of merging music and computer worlds. With his friend who taught him to program in machine language, he wrote a music program that could play music from inputted notes *(back then, there weren't any programs for computers, right, the computer didn't have a mouse, like I don't think the Macintosh had even come out yet, so this is pretty early, um… it's just a keyboard and a monitor, you know. And there was a, you could buy a card that goes in the back, like a sound card, and it could play, it could play notes, um cause before that all the–without the card all that it could was just little beeps, so my dad got me two of these cards, and with those two cards, I could play, I could play 12 notes at the same time, um and it sounded pretty good, it was kind of like a real synthesizer… and we got this program to work where essentially, you would type, you would enter data for the notes, and then it would play it).* Together they programmed the Festive Overture by Shostakovich *(which is a great piece, I think I was into in because I think we had played it)* and then Ernie programmed the first movement of Beethoven's Ninth Symphony. This type of activity, of entering musical data, eventually became too time consuming for Ernie and he lost interest *(I'd look at the score, type in the note, you know, type the note in, type the duration value there–whether it was loud or soft, and um just did that for hours and hours and hours).*

Ernie did not formally study computers in high school but had a lot of advanced math. He admired his Math teacher of senior year, Benjamin Levy, who made the students feel good about themselves and about math *(by the time we were in twelfth grade we were already, we were in the highest calculus level. And when we were in the second half of the year, you know we had already taken all the tests, the qualifying tests and all the AP tests and all that stuff.*

So it was actually kind of, you know we did just a lot of sort of um, ah chatting in class. We'd order pizza… You know it was kind of nice. You know he made us feel pretty special).

With his musical talent and his love of mathematics and computers, Ernie debated toward the end of high school whether to apply for a standard college/university or to music conservatories, which focus only on music. He finally decided to go to an academic college where he could do both music and computers *(and this was kind of a tough choice, I ended up going with, you know, sort of a standard college which I think was a good idea because it meant that I could do much more than just music. So if I had gone to a conservatory I would only be exposed to music and that's it… like if you went to NEC and all you do is music and nothing else, um, whereas with MIT, ah I mean primarily I was doing engineering, but there was so much music I could do at MIT that it was really kind of a nice balance of both… choosing to go to MIT over music school, that was an enormous, really important, you know thing that happened… you have to choose what one are you going to do, and I choose one, and I think in retrospect I think it was a good decision).*

His initial interest during his MIT undergraduate was the hardware lab where they built computers by connecting chips and wires together and programmed in machine language, which requires one to understand how computers work. During his senior year at MIT, however, Ernie discovered he was no longer excited about the hardware part of computers *(it was all about creating chips and parallel architectures and multiprocessors and memories and connections between all of them, and all that stuff. It was fine but I just wasn't excited about it).* After a casual encounter with a professor from MIT's Media Lab,[61] Ernie decided to abandon his hardware engineering discipline and move to the Media Lab *(was a huge, hugely*

[61] An interdisciplinary research laboratory devoted to projects that integrate technology, multimedia, and design.

important moment). Ernie, not a big believer in much planning and thinking ahead feels that at each moment throughout his life he has been trying to make the best decisions for that time. He also believes that luck sometimes played a role too *(when you go and make your decisions, you make the best decisions you can at the time, but I'm not, I'm not a big believer in planning, um, or ah, you know, trying to think ahead so much, I think you kind of try to make the most reasonable decision you can make at the time and hope for the best).*

Another big, though not difficult, decision in Ernie's life was to start a company with his colleague after they both graduated from the MIT Media Lab *(when we were graduating from the Media Lab, you know, Alex said, "hey do you want to start a company?" and he and I said "sure," it just seemed like, maybe that wasn't a hard decision just because it seemed so,* well *"hey if there's an opportunity to start a company you should do that").* Ernie knew that otherwise it would have meant settling on a non-ideal career path *(go get a job at Microsoft and it would have been a much more, sort of standard thing).*

Before joining MIT, Ernie did not pursue music as a career *(I didn't think of myself as a professional musician at that point. You know, um, I did music and I liked music but I didn't know what level I played at compared to others)*. However, since graduating from MIT, Ernie improved in a significant way musically *(like I think musicality and my, you know, a lot of my music ability has gotten better since graduating from MIT).* He has occasionally entertained the idea of having a full-time music career, but this would require that he quit his job at his company, Harmonix, which is like leaving his baby *(a lot of it has to do with this company and wanting to stay here, and I love what I do here and I like the people that I'm with and, you know, … Alex and I are like the heads of the company, it's a 250 person company, you know, like you can't, it's kind of like leaving your baby, emotionally it would be* *very very difficult for me to leave here).* Ernie believes that he does have a professional (or semi-professional) career in music. He performs with professional musicians and gets paid like them, but he only does a fraction of what they do in terms of the time they devote to music-making *(I kind of have now… I don't know what to call it… is it semi professional? I mean it's, I play with professional musicians, I get paid like professional musicians, the difference is that I only do one-tenth of what they do. So, ah, they have a, you know, a fully fleshed out music career, they perform in multiple ensembles, they teach, they–you know–they do all that stuff, right, and, so I just have that little sliver).*

Ernie combined music and computers in his life numerous times. After first programming his Apple computer to be a music synthesizer, he moved on at MIT to build a system that could recognize the pitch of single notes as well as harmonies of played music by using signal processing, specifically Fourier transformations, similar to how speech is recognized by computers *(I think it was really fun project for me to work on. You know it was one of the first things that I did that combined things like that, and, and I really liked it too. From doing that I kind of understood that there could be things, you know in the world related to computers and music, or signal processing, you know that I found pretty exciting. The whole signal processing, you know, world of electrical engineering was really what I was most attracted to. So I took a bunch of signal processing classes also towards the senior year, and also when I was in graduate school, and those were pretty, you know, I always found those pretty interesting).*

The third time was when Ernie discovered the magic world of technology combined with humanistic aspects, at the basement of Mike Hawley, a fellow at the Media Lab and a pianist, who owned a nine-foot Bosendorfer grand piano, custom fitted with solenoids to be a MIDI piano *(and it was a completely different world, it was so exciting there, because the Media Lab is about computer science and art, or about how 'society should use computers,' you know, they think about sorta how technology affects society and people, you know, it's much more humanistic).* It was in this project that Ernie used his favorite Lego blocks to integrate his two worlds of music and computers together, constructing a piano-roll player that would listen to music encoded in piano roles used by piano players in the 1920s and play it *(it was the most incredible thing, and you, you know send MIDI into it and it would play, it sounded amazing).* His next project combining music with computers was at the MIT Media Lab, working with Tod Macover who was running the computer-music group there. This experience shaped Ernie's current identity *(which is completely combining computer programming, engineering, and music.)*

The ultimate combination of computers with music occurred when Ernie co-founded his company, Harmonix, developing products such as Guitar Hero and Rock Band that simulated the feelings and sensations performers have when performing music *(even though you're not actually playing right, it's just, you're pushing some buttons on a plastic instrument, but there's something about how we did those games that makes you feel like you're playing, you know and I sometimes kind of, I can, I can understand we've captured that feeling because I know what it's like to perform, right)* (see Figure 3).

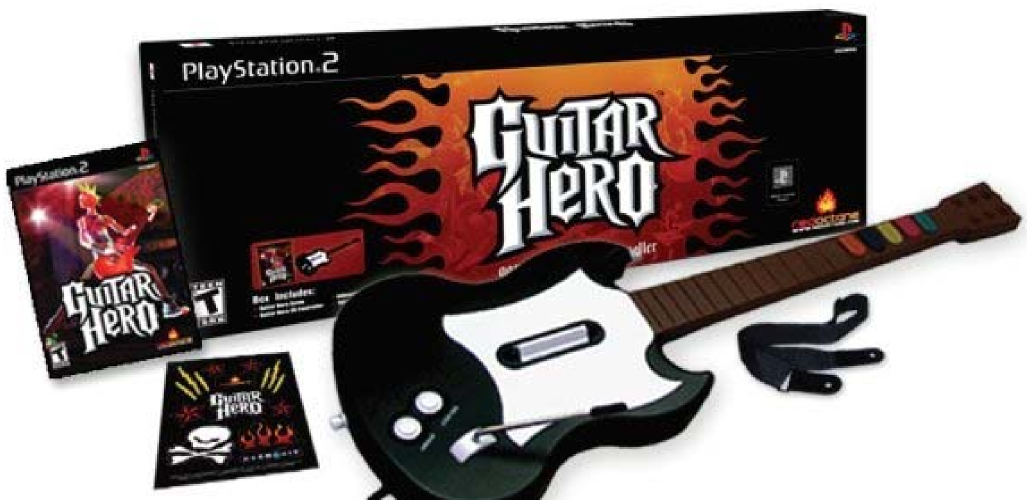

Figure 3: Guitar Hero by Harmonix.

Ernie attributes a lot of his interest and success to his teachers, both music teachers and math/computer-science teachers. In addition to his favorite high school math teacher in his senior year, he recalls excellent professors of math and computers at MIT, Prof. Grimson, Prof. Rod Brooks, and Mike Hawley. His first computer-science class at MIT, taught by Prof. Grimson who taught robotics, is memorable as it was here that Ernie first learned about computer programming languages formally. Ernie even recalls the exact name of the class and its number ID *(the class was called "Structure and Interpretation of Computer Programming," um, also called 6-00 1… Ah anyway it was a very important class you know that was the first real college level class, when I was a freshman, that you know like I was learning stuff I had never seen before in high school. Everything in math and physics I'd already seen some, but this was all completely new stuff so it was pretty exciting).*

Ernie also had some great clarinet teachers. After starting off the clarinet with his kind clarinet teacher, Louise Goni *(she was very nice and very caring and um, but not overly demanding*), he had an intense experience for 18 months during high school with his second teacher, Jonathan Kohler, who had a strict style of teaching *(he was extremely demanding um and set up these standards of performance and practicing that I thought were crazy, you know, he said " you have to practice three hours a day" and I said, "but I don't think I want to be a professional musician," he said, "it doesn't matter").* Kohler affected Ernie's musicianship, in particular helping with his confidence and stage presence *(he taught me how to practice for real and he taught me about kind of like these quality standards to hit, you know, he like had stage presence, you know, when he played, he was very confident, you know, he could um… I just kind of got an appreciation for that level of musicianship like, it wasn't like a hobby).*

While at MIT, Ernie enjoyed studying the clarinet with Bill Wrzesien,[62] head of the woodwind department at NEC and of the chamber music department at the NEC prep school, *(he was also great, because, you know with every new teacher you get a new perspective),* with whom he learned the Brahms clarinet quintet *(which is, you know, an amazing piece).*

At MIT Ernie developed musically in a significant way, playing chamber music and performing in the summers throughout his undergraduate and graduate years *(MIT was fabulous for music, I think I developed musically quite a lot, I played a huge amount of chamber music, um so every semester they have a, the MIT Chamber Music Society… so we would form our own kind of impromptu groups during the summer time with a group of friends who all got to know each other, we became really good friends and played music together… we played just a lot of pieces at MIT with some great coaches, David Deveau who's a pianist, Jean Rife, she plays French horn, John Harbison, he was coaching us, he coached me for the Brahms clarinet quintet, and Marcus Thompson, really great coaches,*

[62] Bill Wrzesien was first clarinetist for the Boston Ballet and Boston Pops, and occasionally played for the Boston Symphony Orchestra (BSO).

and I think that did a lot for my music playing). Throughout MIT and after graduation, Ernie participated in the MIT Gamelan[63] group through which he befriended the founder of the Radius[64] ensemble, of whom he is a permanent member to date (see Figure 4).

Figure 4: Ernie with his Radius Ensemble.

Ernie attributes his engaging in computers and music to two distinct reasons. First, his love of computer science comes from being attracted to building things *(I think I've always been attracted to building things, and the nice thing about building software is you get to see kind of results instantaneously. To build something and then you get to see how it works right away. And so it's a very ah, it's very fun to be able to build systems and see how they work. So I always liked that).* Secondly, playing his clarinet grants him emotional satisfaction and affords him with a powerful way to connect with people *(and then for music I think it's um, you know emotionally it's very satisfying to be playing music and–you know I was just playing yesterday, oh I mean on Saturday at a house concert. And you know it was just really nice to play these pieces. We were playing some Brahms… the two clarinet sonatas. Anyways*

[63] Gamelan Galak Tika is a Balinese percussion and vocal orchestra, resident at MIT.

[64] A Chamber music ensemble in Residence at the Longy School of Music, Cambridge, founded in 1999 by oboist Jennifer Montbach.

it was, ya you can really connect with the listeners, and it's just a very powerful sort of um, you know way to connect with people).

Music is part of Ernie's identity *(it helps me with who I am),* as his life would be somewhat boring without it *(if I was only doing engineering then it would be a little boring).* Music adds artistic and creative aspects to his life as well as opportunities to interact with people who are different from the people he meets daily at work *(so it's nice having those two different, you know, different groups of people to be able to interact with in different ways).*

It is often refreshing for Ernie to engage in rehearsals during his work day *(I'm doing things that are different than what I'm just doing at work… I show up and, you know, they're talking, and you know, we kind of, it takes a little bit, it takes about 10 minutes to get going, and you're saying how are you and how's it going, and all this stuff, then we start working on the piece,* and *then you know we get into it and actually working and focused on it, um and then after two hours I'm kind of packing up my instrument and going back to work).*

Ernie suggests that he learned his social skill of collaborating and communicating with people from playing music *(learning how to work with, with people playing music, you know obviously it's a pretty important skill, right like, you need to get along, you need to understand how to resolve conflict if you have different interpretations for something, you need to know that you have to come in being prepared or else you're disappointing the other members of your group).* Ernie cannot identify which discipline informs which with respect to the development of his social skills, but he knows he is applying the same kinds of skills in both disciplines.

Music practice has awarded Ernie with the feeling of achievable progress when he captures a musical piece that initially seemed impossible *(your fingers are trying to execute this very complicated technical thing and they just can't do it yet, and you start off and maybe you use a metronome so you start off slow and kind of build up and get it better and better, and all of a sudden you know after a few hours of working on a passage you can do it. It's like, my fingers could not do this before and now they can do it, so something, you know, I changed something in my brain, to cause my… to give me the ability to do this, and so there is this very palpable sense of progress, you know which is really wonderful when you're practicing something and you're getting better you know).* This feeling, which is measurable and tangible in the context of music but less so at work, provides Ernie with a good road map when he tries to achieve challenging goals at work *(so it kind of gives you the sense that oh yes I still, I can still do things and I can keep getting better at things... and sometimes it's a little harder to tell at work, … it's harder to measure that, I mean you can, you sort of do things, but I'm talking about the ability to improve yourself as a person, you know to actually become better at your job, to, you know to, to do stuff that you actually couldn't have done before and, you know, at work it's much hard to measure that it's harder to tell what the boundaries are, and you know)*.

Ernie always has music tunes in his head except for when he needs to focus on work. As soon as, for example, his meetings get boring he starts thinking of music again *(I'm always, you know I'm usually tapping rhythms a lot* [taps on legs]*, you know that kind of thing).* Typically, Ernie cannot listen to music while he works unlike other people he knows, because he gets distracted *(if the music is playing, I have to listen to the music and I'm not concentrating on what I'm doing).* He focuses on whatever he is doing at the moment and when focused on work, music is not in his head. However, music is part of what Harmonix is all about, so music is there at work in that way for Ernie *(it's part of the discipline).* As he has gone more into management (currently, the Technical Director, with the engineering manager and VP of Information Systems and Technology reporting to him), he became more involved with the business aspects of the company and less with the technical aspects *(honestly now, I haven't written any code for Harmonix, for–it's probably been four years)*, and misses programming.

In playing his clarinet, Ernie distinguishes between working on performing a piece and working on practicing. When Ernie works on performing a piece he is focused *(the best kind of playing is when you are ah, that's all you're thinking about. I should be completely in the zone).*When he works on practicing *(it's really just about making my fingers move accurately,* a*nd the metronomes going),* it feels like daydreaming, as if he is doing something physically mundane with the clarinet that he can think of work *(I mean I'm physically doing something right, I'm physically playing the clarinet, and I'm aware of whether it's, whether it's working ok like are the notes even, you know, did I, did I miss a note, I'm aware of that, but because it's so mundane, and it's really just an exercise then I can think about other things… so I can think about work or I can think about other things)*. As soon as Ernie goes into playing for performing rather than practicing, he is only focused on music *(sometimes that happens. You know so then I can do both–but as soon as you're playing, as soon as you're focused on making music, like thinking musically, you know and trying to do something with the music).* So, for Ernie, music and his work are two different things that sometimes he can think of simultaneously *(I think that, they are two,* the*y are two pretty separate things… they are different parts of the brain and they can both work in parallel).*

There are also ways in which Ernie's work has informed his music. Ernie is analytical and his attraction to computer science, building and engineering, has affected how he thinks about music and practicing**.** Ernie thinks of music as having a technical part and an emotional part. The technical aspect of music-making, which people spend a lot of time on, is for Ernie like the engineering mindset–first breaking the big piece into smaller pieces, then practicing each small piece, and finally putting the small pieces together. It amazes Ernie how he can capture a big, difficult musical piece by working on its smaller parts and then putting them all together–like an engineer who works on the design of his big project *(the truth of it is you spend a lot of time on the technical stuff right, you spend a lot of time getting your fingers to move evenly at the right, at the right place at the right time and, you know, having the whole thing kind of um, just being able to technically execute it, and as far as that goes… I think of, I do think of it as very sort of, in an engineering mindset, you know like, okay I have, here's this crazy piece that I'm just working on right now by Joan Tower, and it's um, uh called Amazon, and there's all, you know there's a whole page of triplets, and it's all kind of, it seems random, I don't see any patterns you know, there's no particular scale it's um, okay now I have to figure out how to play this, okay so I break it down, right what do engineers do they break it down into smaller problems, okay so… I start working on one measure, I'm like I'm not going to worry about the other stuff I'm going to work on this one measure, … and then I see how long it takes me to get it… okay so I play it, I start really slow and I kind of build up, okay that, I see that… from, getting from not knowing to being able to play it, um it's not a full tempo yet but you know that took me ten minutes, okay how many measure do I have, okay I have about you know eighty, eighty bars of this thing, okay so when's the concert coming up it's about in a month in a half, okay so I think can, I think I'll be okay, I can, you* *know I can, I can work on, you know what I'm saying I'm just going to break things down into, into blocks, and then calculating whether, you know how it's going to work, and uh).*

The emotional side is added to the music piece once all the "plumbing" (i.e., the technical aspect) has been polished. This emotional side is also part of engineering skills because the final engineered object can be beautiful too. For example, a software program designed to perform a specific task can be written in many different ways. It can be written elegantly or not as elegantly *(you have to have the plumbing and all the stuff to get, you know, and once that's there then you can start thinking about expression … and okay what am I trying to convey in this piece, at that point I don't know if it's necessarily that relating to engineering skills, you know, although there is sort of like, there's um, I also think of engineering as sort of having a technical thing but then the result can be beautiful too, you know if you, if you're programming, if you're programming something there's a, you know, there's an elegant way to do it, you know and uh, and if you do it in the most natural elegant way, which you know is not obvious, it's, it's hard to the, the best solution to something, you know, I need to write a program that does a certain thing, and there's lots of ways to do it and most ways are not right–well I don't want to say not right but, they can yield the same result but the way that you did it was not particularly good, or, or um elegant you know, or solid, right, just like when people build a house, you can look at the house, and you'll have no idea if the plumbing is done the right way, so you move in and a year later the whole house is falling down, or you move in and it lasts 100 years, it all depends on how it was built, right).* Ernie has a special appreciation to aesthetics and beauty. He does not know whether this appreciation comes from his engineering side or from the music side but it definitely exists in both *(I have an appreciation for that being important, you know, for doing things the right way, that's important to me. And for not just* *kinda doing it some sloppy way, you know… I think of wanting it to be technically sound, you know technically strong and elegant, and I want that for both, right, for both the engineering thing and for how I, how I make music, so kind of mutually reinforcing there).*

Because of his analytical mindset and his experience with classical and romantic music that lends itself to patterns, Ernie can identify patterns also in modern music where patterns are not as obvious, helping him learn the piece faster and better *(it has a tonal center but it shifts around a lot more so … if you just start playing it initially, you're like I don't know where this is going is this atonal or what? But then you look at it more closely and then you realize like oh I see, oh it is, it is, he has tonalities he's just changing it every beat, you know, he has this like, he has this scale, he'll play four notes of a scale in C, C major, and the next is F sharp major and C major and F sharp major, and he just, oh okay I see that's what's going on, so, you know you kind of, that kind of analytical uh, that thing helped, you know helps you um, helps you understand what is going on in the music and then helps you learn it better).*

Playing the clarinet in addition to work is challenging for Ernie as he must be disciplined about his daily schedule juggling between Harmonix and home, especially around performance times. Recently, Ernie has developed routines that work for him especially when he has upcoming concerts. For example, in his morning routine, after breakfast with his wife and two kids, he alternates bringing the kids to school with his wife, then returns home to practice for an hour, and then goes to work by 10 am. These routines are very tight and have no room for error. His evening routine includes seeing his kids to bed, followed by a dinner and chat with his wife, and sometimes practice if he did not practice in the morning. When concerts are approaching, like his upcoming March concerts with the Radius ensemble and his all Brahms program with

Mike Hawley and with his wife in Rockport, Ernie has to integrate into his schedule rehearsals, either in the evening or during the day *(I'm working with all professional musicians, you know, they don't have a day job, and so what happens there is that, sometimes I have to have a rehearsal, say from noon until 2, and that's smack in the middle of work, um and if that happens then, you know, that's how it is, I set up my calendar and I have travel time before the rehearsal and travel time after, so I usually have to take 3 hours off of work).* Although midday rehearsals present a challenging and tight schedule for Ernie, it is still a wonderful feeling for him *(I don't think of it as bad, you know, I actually think of it as this nice, very different thing that I'm doing right in the middle of the day).*

Music in Ernie's life has always been present continuously as well as sporadically, depending on the time period in his life. After college, Ernie had to be more proactive in keeping continuity in his music-making because he no longer had the orchestra outlet that MIT provided him with *(unless you're going into music professionally, it's very difficult to continue playing*). He continued attending yearly Apple Hill summer music workshops that he started as an MIT student and joined chamber groups in parallel to his work commitment. In general there was never a period in Ernie's life in which he did not play music, although there were periods in which he took off from the clarinet, like the Gamelan period and also in the summers *(I've been pretty much involved in playing music continuously*). Playing with the Radius Ensemble has been a steady gig for Ernie *(we'd do four concerts a year, plus various other things, all in total, if I look at a whole year, I'd probably end up playing something like, you know, seven, seven or eight concerts, depending on the year).*

Ernie views both music-making and computer-science projects as a combination of individual and team work *(it's really both, and you can't have one without the other… so* *when you're working as a team, ah, you need to ah combine all your efforts in the right way so that the end product is something you can achieve as a team and something that you can achieve as an individual).* As a clarinetist, who mostly performs with others, Ernie has to practice his part on his own after his group rehearsal. This is analogous to the work style at Harmonix *(where you come together for meetings and you have to make sure everyone's lined up and doing the right thing, but then you go back to your desk and do work by yourself and do the part you're supposed to be working on).*

Ernie would not have liked his life without music, even though it takes away free time from him *(if it went away for a long time I would be kind of sad).* He compares the presence of music in his life to having his kids *(all of a sudden it takes an enormous time but I managed to hang on to).* In order to keep music in his life, Ernie made compromises–no TV, no movies and no Facebook *(but I've managed to hang on to the music part, so all the other stuff went away… you know like there's all these things that other people do with their time that I just don't, because I'd rather, I'd rather do other things).* Music has directly contributed to Ernie's professional identity, as he would not have this profession if he wouldn't have played music *(this is because my profession is about combining the two together, which is not a very common case I think, you know so I'm very lucky in that sense).* Ernie would have felt bad without computer science and engineering in his life as well. He still does some small programming jobs at home even though he is in a management position at Harmonix, because he misses programming.

Ernie thinks that overall, he is pretty happy. This is because he experiences two worlds, music and computer science, that most other people do not *(I mean people have, you know, overall have a variety of experiences, but there are some people who, you know maybe they* *just have engineering and they don't have this extra thing, you know, and I think having the two just makes the world much more interesting).* The fact that Ernie connects with two different groups of people (i.e., musicians and computer scientists) makes life interesting for him *(I don't know if they're necessarily completely different people but they don't interact, you know usually the musicians are just, musicians and they interact with musicians, and there's there, there's the professions whose job it is to do programming and that's what they do, you know they all have stuff that they're interested in like skiing or whatever, but you know, but I'm pretty intense on both and I think that makes life more interesting).*

Playing with the MIT Gamelan group sharpened Ernie's somewhat weak memorization skill *(I don't know how you deal with the memory slips)*, as all players learned their parts by listening or by someone demonstrating, with no sheet music *(it's this kind of amazing thing that, feeling of like, you don't ever have to worry about forgetting or a memory slip, because you never … you never, exactly you never had to rely on anything but your memory in the first place, right, whereas if you're using sheet music, and then, where you learn the piece and then you have to memorize the piece, you know it's like, it's like a two step process).* When Ernie had to memorize music recently, he practiced similarly to the way he practiced with the Gamelan group *(sometimes when I had to memorize stuff recently, like I played… there's these Bach transcriptions of the cello, these transcriptions of the Bach cello for the clarinet, uh and I played a couple of them here and there like one for a wedding for my friend, uh, and I had to memorize it, so what I did there was I, I listened to it a lot, and I got it just to the point where I barely knew the notes, and then after that I just stopped looking at the music and I would practice it, and half of what I was trying to practice was like, oh … does it go like this or does it* *go like that, and just using my ear to figure out what the notes are, you know I was trying to get away from looking at the music as soon as possible).*

When Ernie plays the clarinet he senses time moving in an interesting way that is made up of two experiences. One is the actual playing of the music and the other is a simulation of the real experience in which you are thinking about the fact that you are playing the music, which are the same kind of feelings one has when playing Guitar Hero.

In summary, the main ideas in Ernie's story are:

- Has analytical mind;
- Liked math from an early age and was good at it;
- Was initially inspired to play after watching a TV program on musical instruments;
- Participated in orchestras in youth, and in chamber music groups throughout adulthood;
- Inspired by musician role models while in musical groups in youth;
- Aspired in youth to be the best player in his musical groups;
- Bonded with family members through music (e.g., parents drove to music rehearsals in youth, plays with wife);
- Bilingual;
- Parents did not push to play music;
- Persistent;
- Curious;
- Diligent;
- Had space and freedom to explore ideas as a student;
- Sees the aesthetics in both music and computer science;
- Feels in the zone while performing;
- Applies divide-and-conquer methods when practicing musical pieces and at work;
- Juggles between work and music performance continuously throughout his life;
- Acquired an academic degree in computer science with a minor in music and then proceeded to a graduate degree in computer science;
- Uses music practice as a benchmark for evaluating and making progress at work;
- Uses music practice as a practical scale (e.g., coping with a musical piece that initially seemed impossible);
- For measuring progress and applies it to his work;
- Combined music with computer-science in real products;
- Experience with pattern recognition in music informed his general pattern-recognition skills that he can apply also in modern music, where patterns are less obvious, enabling him to learn pieces faster;
- Recalls favorable music teachers and computer-science mentors;
- Always has music tunes in his head;

- Appreciates both individual and team work;
- Rehearsals during his work day are refreshing for him as he is doing something different;
- Likes the social aspect of playing with groups;
- Connecting with two different groups of people (musicians and computer scientists) makes Ernie happy;
- Performance makes him nervous;
- Difficult to identify which discipline informs which with respect to the development of his social skills, but he is applying the same kinds of skills in both disciplines.

B. Stan

When Stan practices music at his home in Belmont, Massachusetts, he does it without his instrument, the timpani (see Figure 5) *(my percussion equipment fits in a briefcase, it's a bunch of sticks).* The timpani are big and heavy to carry *(it's not practical for me to take, when I play in the Concord Band I use four of them, I would have to have, a huge truck to carry them, and I'd have to have servants to help me carry them inside, so most organizations have timpani, and if they don't, it's quite a significant deal for them to a, to, they usually have to rent them, and the players typically don't have them, including, I'm sure, symphony players, I don't think they have their own timpani*). He practices only with his mallets and score, simulating the coordination and tuning of his drums *(the things you have to practice with timpani, are, which notes do you hit with which hand, cause it matters because, when this hand finishes hitting this note, it's probably gonna go to a different drum the next time, and you have to, you can get very tangled up if you start, if you do things wrong, so you can hit this, and then go over there ...)*. He practices, especially the hard parts, by imagining and plotting out which way he should do it, and the more mundane ones he can figure out during rehearsals or performances.

Figure 5: Stan with percussionists of the Concord Band, surrounding their newly purchased timpani (kettle-drum) which was supported by IBM (51 Walden - town's performing arts center, Concord, MA, 2004).

It was not until around 6th grade that Stan picked up the drums, casually responding to his elementary school teacher's search for volunteer drum players in the school band *(so a whole bunch of us stood behind a bench with drumsticks and she taught us how to play the drums)*. It was during high school that Stan developed a strong liking to the drums, playing timpani throughout high school in various school groups and at the Brookline Civic Symphony conducted by Harry Ellis Dickson.[65] After being introduced at age 15 through his mother's contacts to Vic Firth,[66] an NEC[67] percussion professor and principal timpanist of the Boston Symphony Orchestra (BSO), Stan began his percussion lessons.

[65] Harry Ellis Dickson (1908-2003) was associate conductor of the Boston Pops, founder and conductor of GBYSO, and first violinist of Boston Symphony Orchestra.

[66] Vic Firth also founded the Vic Firth Company–a percussion stick and mallet manufacturing company that recently began manufacturing rolling pins, as they resemble drumsticks. His company manufactures 90% of the drumsticks used.

[67] New England Conservatory.

When he was a senior at Brookline High School, Stan was recruited by the director of the MIT band and orchestra and also joined GBYSO, where his music life flourished. Although Stan was not aware of it at the time, one of his GBYSO colleagues was John Adams, the famous American composer, performing at one point with the orchestra Mozart's clarinet concerto in A major *(so that was a big treat being in the symphony*).

Although mostly playing the timpani, Stan also played other classical percussion instruments such as the snare drum, bass drum, cymbals, xylophone, vibraphone, marimba, bells, triangle, and wood blocks. Still, his choice of the timpani as his primary instrument restricted him to playing in bands or orchestras, as it is not an instrument that one performs solo or in a chamber group *(when you play timpani, there aren't too many places you can go to play, you go to the music room (laughs) cause that's where they were, so I played in organized groups, in the high school, that's the main time that I really got into it*).

Stan was self-motivated to play percussion in his youth *(I had borrowed a xylophone from the school… which I would play).* His self-motivation was complemented by the compassion of his primary school percussion teacher, who offered to lend him the school xylophone *(she just sort of offered it, it was a novelty, it never occurred to me).* He favorably recalls her telling how she got confused in the subway by her ambidexterity. Stan's self-motivation was accompanied also by the excitement Stan felt when he began his percussion lessons with Vic at NEC *(it was a certain excitement about that… it was, something, um, that I felt good about… he was sort of a mentor)*. During his lessons on Friday afternoons, Stan would also learn from his teacher about the inside events at NEC *(he's very dynamic, so he told me about not just the music, you know, I'd hear some of the politics about it, he'd tell me that the guest conductor got lost today, … so I was getting a real insight into the music business, as well as from a first-rate person).*

Their relationship carries to date, as Stan recently bought from Vic's company a rolling pin for his wife, bringing them to reminisce over the phone.

A large part of Stan's self-motivation to play percussion was social *(It was a, a community, so I, I enjoyed classical music, it was a community of other people who liked it, and we played things, you know, play in the band together).* He recalls missing, due to being sick, a rehearsal with the Brookline Civic Symphony to which Harry Ellis Dickson brought his friend Danny Kay, who was Stan's favorite comedian.

Prior to the drums Stan took piano lessons but never practiced enough, and never really liked it or got good at it. His piano at his home in Belmont, a 1898 Mason Hamlin, was purchased by his father's family in the 1930s for about $36 and was brought to his parents' home in the 50s in a terrible condition *(my mother refinished it, she completely took it all apart, personally herself, and ah took it all apart, refinished all the pieces, painted, it was black, and had the insides professionally done).*Unlike percussion, Stan was not self-motivated to play the piano *(I liked the idea of playing the piano, but I didn't like practicing enough to actually do it).* He was also not particularly encouraged by his parents to play the piano *(so that's why I don't play very well).*

In the fifth grade, at about the same time Stan began practicing percussion, he became aware of his liking and being good at math *(I was always good at math, and liked it, and looked forward to the next things in math)*, thinking that by sixth grade he would know it all. During his undergraduate at Tufts University he majored in math, impressed by the math professor who taught him Real Analysis, his first serious math course and the basis to calculus. After graduating from Tufts, Stan continued at Stanford for his master's and Ph.D.

in math focusing on ergodic theory[68] *(I decided for whatever reason, to go onto graduate school, in math, that is, I couldn't think of something that I wanted to do more at the time, so I happened to get into a very good graduate school, Stanford)*.

Stan was introduced to computer programming during his Tufts summer jobs, working for the John Hancock Insurance company, arranged for him by his father who sold insurance. He programmed in their actuarial department on the IBM 1620 *(which was a huge machine, it would have taken up this whole room… sort of mathematical computer, so we would program various algorithms, on that, on punch cards of course, so I learned to program very early)*. There were no computer-science departments in universities during his undergraduate. After graduating from Tufts, Stan continued programming for one year at the National Security Agency (NSA) in Maryland, followed by his enrollment at Stanford for his graduate degree in mathematics *(in college I wasn't sure if I was going to major in math, but I ended up majoring in math, and I decided for whatever reason, to go onto graduate school, in math, that is, I couldn't think of something that I wanted to do more at the time, so I happened to get into a very good graduate school, Stanford)*. Although Stan barely used a computer while at Stanford, he had friends at the Artificial Intelligence (AI) lab as well as at Xerox PARC[69] which just opened. His first real job after graduation was in academia, teaching calculus first at Brown University and then at Amherst college. While at Amherst, Stan started taking computer-science courses toward a master's degree at UMass Boston as he knew some professors there from his Stanford days.

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[68] A branch of mathematics that is an abstraction of statistical mechanics.

[69] Palo Alto Research Center.

From that point on, Stan's career gradually shifted to computer science, starting with summer jobs in 1969 at DEC[70] that led to a permanent job in 1979 with their research group, and to quitting academia. During his 18 years of tenure at DEC, Stan worked at their AI and LISP[71] development groups and ran a system performance and modeling group. One of his memorable projects at DEC was as the engineering manager of a successful network switch project *(that switch itself had revenues of a billion dollars, extremely profitable, and uh, demanding and exciting)*. As its manager, he had to interact with a wide range of people including customers, hardware designers, software designers, and manufacturing and marketing people, and he had to troubleshoot problems *(there were many nights when I was at home or in the office, logged into the switches trying to figure out what was going wrong, looking at the logs, or I would get called)*.

While representing DEC at MCC[72] in Austin, Texas, responding to the Japanese Fifth Generation Computer Systems initiative,[73] Stan was introduced to people from BBN, his current employer.

Stan's musical life flourished especially while in graduate school at Stanford University *(I did a lot of music at Stanford, I did a lot of music, little computer science, and of course a lot of math)*. Pursuing music became a social endeavor as he picked up the recorder and joined early music groups, playing both the alto and soprano recorders with colleagues and

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[70] Digital Equipment Corporation, or DEC, was a major American company in the computer industry and a leading vendor of computer systems, software, and peripherals from the 1960s to the 1990s.

[71] A computer programming language that was used mostly in Artificial Intelligence applications.

[72] Microelectronics and Computer Consortium the first, and at one time one of the largest computer industry research and development consortia in the United States.

[73] The Fifth Generation Computer Systems project (FGCS) was an initiative by Japan's Ministry of International Trade and Industry, begun in 1982, to create a "fifth generation computer" which was supposed to perform much calculation using massive parallel processing.

faculty in the university courtyard several days a week *(it was very casual, you know, we knew each other by first names… the department was, well, it wasn't very small but people just knew each other, ya we'd a, go to his house, and I'm trying to remember if my advisor played, I can't remember, he might have).* He particularly enjoyed playing the recorder with one Stanford professor with whom he also shared interesting discussions *(he was sort of a, free spirit, in general, and um, I was in graduate school from the, in '67-74, I don't know if you remember that time? A lot was going on, politically and, socially, so um, he was, with it, you know, with it, he was doing for himself, he was reinventing himself, as well as teaching his classes, he was someone who was just questioning his, you know, choices in life, sharing those discussions).*

At Stanford Stan also played with the Stanford Orchestra, became a member of Alea II,[74] and took music courses. Aware of his mathematical knowledge, some music faculty engaged in discussions with him about the mathematical foundations of music, only to be discovered later by Stan that one of them was the famous John Chowning,[75] inventor of the mathematics behind the synthesizer *(he was always asking me math questions, about Fourier series,[76] and things like that).* His musical life continued in the east coast while teaching at Brown University and Amherst College, playing percussion with their orchestras and frequenting concerts in Boston.

It was at Stanford that Stan revisited piano playing, when he and his housemates rented a piano for their group house *(and just taught myself how to play some things, not very well, but I could play them all the way though… some simple Bach things, some Scott Joplin).*

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[74] Alea II is a contemporary music ensemble founded by Theodore Antoniou at Stanford University in 1969.

[75] John Chowning (born in 1934) is an American composer, musician, skilled percussionist, inventor, and professor best known for his work at Stanford University and his invention of FM (frequency modulation) synthesis.

[76] Fourier series are used to express periodic functions like the ones that comprise signal waveforms.

During his time at DEC, Stan had long periods in which he did not play the timpani at all due to his workload, except for occasional gigs *(I remember one time, someone wanted me to play in an opera, a performance, some, some community group was doing, and need a timpanist… Yeah, I did that… I had to go to the rehearsals).* However, it was while at DEC, and already married, that Stan revisited the piano for the third time, taking private piano lessons from a Longy School of Music[77] teacher for several years *(I decided that, "Gee I think I'm gonna do this")* until he could play some Beethoven Sonatas and other pieces at that level *(I remember the last lesson I took from her was, the day before my son was born, and after that I didn't have time, for a long time)*.

A coincidence brought Stan to join the Concord Band[78] in 1999, when his son's saxophone teacher who was also the band director, discovered that Stan is a percussionist and invited him to play with the band. At the Concord band, Stan plays traditional marches, 20th century music (1930-1960), Mozart and Beethoven arrangements, commissioned work, and modern pieces. The band is made up of woodwinds, brass and percussion, with occasional bass and piano, and seldom strings.

Presently, Stan works at BBN where he feels more flexible with his work hours than at DEC, making it easier to fit a regularly scheduled music time of Monday night rehearsals, as well as occasional Friday night dress rehearsals, and concerts. With the Concord band, which has existed for about 50 years, Stan performs 15 concerts a year–summer concerts at the Fruitlands Museum at Harvard, four pops concerts featuring a Boston Pops' style sit-down dinner, which are the real moneymakers, and two more formal concerts. Despite two recent

[77] A conservatory in Cambridge, Massachusetts.

[78] The Concord band is a community band based in Concord, Mass. It used to be conducted by Bill McManus, a clarinet teacher who used to be the director of music in the Belmont Public Schools.

shoulder surgeries which caused Stan not to practice, he made sure not to miss the major fall and spring concerts *(because they are the most serious ones).*

Stan does not think about his music while working *(you know when you're working, it's harder to make time for that, especially if you play a big instrument where you can't carry it somewhere)*. Being frequently conscious of music prevents Stan from thinking of music while focusing on his work unless that music is not interesting *(I'm always conscious–not always, but frequently conscious of music, although I do not play it as background, because I, somehow if it's music I can take as background, then it's usually not very interesting, and if it's interesting, I'm going to actually listen to it and not have it be the background, so when I'm working, I do not typically play music)*.

Stan speculates that playing an instrument other than percussion would have made it easier for him to pick up gigs and perform, something he could have done with the recorder *(just call someone up and say let's play some chamber music Thursday night cause I'm free… I could have done that if I kept up my recorder… I think I thought of doing that a couple of times).*

Since Stan's practice at home does not include his instruments, he developed his own specialized practice methods *(there are various strategic things you'll have to figure out for percussion).* For practicing tuning, Stan plots the four drums to figure out which drum will be used for which note *(there may be the case where you have to make, need more than four notes, and so you need to frequently change them, and sometimes you have to do it very quickly… so you need to plot out, each drum has a different range, and you have to figure out, well, if I'm gonna get from these four notes, and need another note very fast, which one of these am I going to use? You can't figure that out in real time, you have to plan it).* Alternatively, Stan may listen to a CD with the recordings of the pieces the band plays, *(observing my part, and figure* *out what's going on).* Occasionally Stan would practice his xylophone part on the piano at home by using two fingers *(you get to know the notion of where it is, it's not the same, but you can get a little head start)*. In addition, he may simulate the performance by reading the score while holding the mallets in his hands, especially for the hard parts. Finally, Stan may not move his hands while practicing–but would rather imagine his hand movements *(I'm just imagining it when I'm home, I'm not actually playing it)*. The more mundane parts he can figure out during rehearsals or the performance. Sometimes a week would pass in which he would not practice at home until the next rehearsal. There is little enjoyment for Stan during his practice *(because no music results from it… because it's not, it's not like playing the piano or playing the clarinet).* Sometimes Stan wishes he would have played another instrument that is more versatile and more portable than the Timpani, like the clarinet *(my son plays clarinet, and I, sort of envy him, because he plays a lot of instruments, he plays piano, and electric bass, and sax as well, so it's much more portable… you can practice the clarinet and it sounds nice, and it stands on its own, and it's a beautiful solo and you can see yourself improving, that doesn't happen for percussion).* With his wide range of instruments and eclectic music tastes, his son plays all sorts of music including classical, chamber music, jazz, klezmer,[79] and rock and roll.

Stan's thinking mode at work is mostly in a gestalt[80] fashion, *(sort of seeing the big pattern as opposed to the little details),* which was popular at the time Stan was in California. He refers to the process of stepping back to see the whole picture as visualization (*I call that*

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[79] A musical tradition of Eastern European Jews. This genre originally consisted largely of dance tunes and instrumental display pieces for weddings and other celebrations.

[80] In gestalt thinking and understanding one grasps the whole thing (holistic processing) as well as the details (linear processing). This type of holistic versus linear processing is depicted in the brain: The left side of the brain processes information in a linear manner (from part to whole), and the right side processes it holistically (from whole to parts).

visually, visualizations, I don't know that it actually is visualizations, but it is my metaphor I don't know that I see anything, but I grasp it at a higher level… I read through details and then try to step back and visualize what's going on… I sort of try to pull back and see a bigger picture of what's happening, but I sort of have to first go through details, without doing that, and then I don't feel I can fully understand it until I fully pull back, and picture it as a whole …).

Stan uses the gestalt way of learning and thinking in each of his worlds of music, work, and social situations, but cannot tell which world first prompted that kind of thinking. During a practice session at Stanford of a challenging Bartok sonata for two pianos and two percussions, Stan had a difficult time getting the rhythms right. Only after using the gestalt way of listening to the whole piece rather than the details of the rhythm, he got it right *(the pianist said, "listen to what I'm playing," and I sort of listened to what he was playing, and I didn't have to count, I just could tell, how what I was supposed to be doing, blended with that, and that's sort of an example where, I looked at the detail enough, but I could only go so far with the detail, and just had to step back, and see how it fit in with the rest, and it was, you know, I could stop counting at that point, whereas, before that I was counting like mad to get the exact rhythm… it was quite remarkable, because it made, what had been the hardest part of the piece for me, the easiest one, because I could just sense what was going on, what it was supposed to sound like).*

Stan uses gestalt thinking and learning also in mathematics to fully understand, for example, complicated proofs. When Stan's advisor first demonstrated the proof of a famous theorem by going through each step like in a classical proof *(you can go through each step of a classical proof, and say, "ok I got this step, I got this step, I got this step," and then you're* *at the end, and you've proved it. That doesn't mean you understand it),* Stan did not get it until his professor provided him with a new perspective of looking at the big picture of the proof.

The gestalt thinking style has accompanied Stan in social situations also *(I used to feel that way as a kid, or even as a young adult, when I was in a social situation, sort of the individual interactions, and I would step back and say, kinda see what's going on here).*

Stan is not readily aware of an explicit connection that occurred for him between the two disciplines of music and math/computer-science, although he became aware of his interest in both at the same time *(I'm not aware of a particular connection, I'm aware of people thinking there was a connection, and then somehow it seemed natural to me)*. In particular, now that he is in management rather than a technical position at BBN, his thoughts about work do not remind him of music *(it's not like, "oh this reminds me of this problem," it's, "oh I thought I had to do something")*.

Although not readily aware of any disciplinary connections, Stan feels that his music performance improves his oral presentation abilities at work, allowing him to experience how nervousness can affect a presentation *(the whole notion of getting nervous about something and getting through that, that probably first happened in musical situations, and so, well I just sort of felt, well I did that for that performance, I can do it for some other performance, and I need to do it, speaking, in my work)*. When about to give a presentation at work, Stan can now lean back on his known feelings before a music performance where he already knows the appropriate degree of nervousness that he felt in order to make the performance work, and apply it to his work presentation *(in music I sort of recognized the right degree of feeling nervous to make this work, so if you're too nervous, you can't play, and if you're not* *nervous enough, you can't play. So I can recognize that in music, and I can sort of now do that in other things, not as successfully because music is much more, constrained in a sense, so I'm, I'm better at music than at other things cause I know how nervous I should feel at a performance)*.

In another disciplinary connection, Stan's mathematical abilities enabled him to do a self-study of scales and harmonies in trying to understand the structure of the well-tempered scale and the significance of the fifth and the forth interval *(cause I could understand the whole ratios, and how, how are logarithms and things like that… you know, so my, my mathematical propensity allowed me to do that)*.

Stan enjoys the fact that his music-colleagues group is a different group of people from his work-colleagues group**.** Although Stan knows people at work who play music, like his colleague from BBN who plays the harpsichord and even built his own harpsichord, he does not get involved with them musically.

Stan likes the social aspect of work, and sees it as separate from the social aspect of music *(I like the social part, and typically in my life, music has been sort of separate social scene)*. This was especially so in college and graduate school *(I had one group of friends, that I sort of did my math and physics classes with, and has as roommates, and then another group of people I knew from the music department, and there was some overlap, but not a lot, so I sort of had two social circles).* Although these are two separate groups, Stan acknowledges that these social circles are sometimes connected, as for example, a player at the Concord band who also played with Stan at GBYSO, used to work for DEC, and used to be married to Stan's boss. Because the Concord band meets only once a week, music is not as social an endeavor as it was in high school or college when they would meet two or three times a week *(so people come from work,* *and practice, and then, it's less social, you know, every so often we have get-togethers, but over the years you get to sort of know them, but not really …).*

Music enriches Stan's life especially in the social dimension *(a lot of it is that it is, it's another life (laughs), it's not that the music is different, it's just that, it's, it's another social, another part of my social interaction, which is separate, well it's nice having more than one, thing to do)*. Stan recalls a talent show at BBN in which he did not participate but observed that there were many talented people, among them many musicians, and that they have completely different personalities than what Stan was used to thinking of them.

Throughout his life, Stan had two major career decisions. He considered becoming a professional musician when graduating from high school, at the peak of his musical career. Using some rationalization, he soon rejected the thought *(in order to earn a living doing that, I would've had to be better at it than I was, and I wanted more to enjoy it than have it be the sole source of my income).*

Leaving academia was another career decision Stan faced, as he enjoyed teaching but did not enjoy the narrowness of his research *(I was in a very specialized field, as all mathematics is, and, you know, how many, maybe there were… 50 colleagues in the world, and it's, I wanted something that's more people related).* He felt his research was of interest only to a small group of people, with little interest from university leaders *(the people who were paying you certainly had no idea at all what the research you were doing was, so why were they paying you? And I, my conclusion was, they were paying you for bringing… renowned glory to their institution, and that wasn't enough for me).* This happened despite Stan publishing papers, but his papers were very specialized and ceased to be of great interest.

Stan's computer-science work became much more rewarding *(I liked it, it was very satisfying, and I was pretty good at it)*.

It is hard for Stan to imagine his life without listening to music regularly, but it is possible for him to imagine his life without playing music: (*if I were not playing in an organization, I might even take up a new instrument, or re-take up the recorder or something like that. But I'd like, I like to be able to take up more chamber music, and you can do that with percussion, but it's harder)*. He imagines that it is possible that people who do not play music lack some understanding that he has of music due to his playing, and thus are not able to appreciate music in the same way as people who play do.

Stan, now in his 60s, is thinking of retirement because his recent role at work has been managing people, which is very challenging for him. He hypothesizes that during his retirement he will also keep thinking about mathematics *(about tricky little math problems, that's just a part of me)*. He sees himself as a person of multiple worlds *(in a sense I have three worlds, I have sort of my social world, my work world, and my music world, and they overlap in different places but they're certainly different, partially because there are just different people in them, but we have friends who play music, and uh, we have friends who are in similar fields, but there's certainly disjointed parts as well).*

In summary, the main ideas in Stan's story are:

- Plays in musical groups throughout his youth and adulthood;
- Self-motivated to play music;
- Has always enjoyed the social aspect of participating in musical groups;
- Was good at math in youth and liked it;
- Does not think about music while at work, as it will interfere with his work;
- Thinks in a gestalt fashion when practicing his music, at work and socially;
- Practices music at home without his instrument (the timpani);
- Believes that music performance has improved his oral presentations at work;
- Believes his math skills informed his music rhythmic skills;
- Enjoys his music social circle as different from his social circle at work;

- Considered becoming a professional musician and also a professor;
- Hard to imagine his life without listening to music regularly, but possible to imagine without playing music;
- A person of multiple worlds: his social world, work world, and music world, all overlapping but different, partially because of the different people in them.

C. Delia

Familiar with the demands of her piano teacher to focus solely on piano practice *(she…was very punctual, and gave all her soul to her pupils)*, Delia kept her parallel engagement in computer science and piano performance a secret for part of her undergraduate studies with Edith Kraus of the Tel-Aviv Music Academy. This burden was relieved when she finally disclosed her secret to her interim teacher, known Israeli pianist, Pnina Saltzman, during her teacher's sabbatical *(she quite appreciated this combination).* While Edith Kraus, student of known Czech pianist and pedagogue, Arthur Schnabel, comes from the German school of music where everything was accurate and deductive, Pnina Saltzman came from the French school of music, encouraging Delia to use her imagination with metaphors *(she has the spice… she gave me a lot to play, a lot of Albeniz, for instance, Spanish music. And eh, when I played she said, "No, no, no. It's not, it's too mathematical. You have to have a fire).* Despite their different styles, Delia appreciates both teachers *(both of them gave me a lot, and moreover the mixture was good for me).*

Delia came from a quite musical family. Her father, from an orthodox Jewish family in Poland, used to sing in the synagogue while praying *(he was in tune and he had also quite a pleasant voice)*. He immigrated with his family to Israel prior to WWII where he became a lawyer and was sent on a mission to Europe to head the Jewish Agency in bringing survivors to Israel, eventually returning to Israel. Delia's mother, from a well-off movie-industry family in Vienna, Austria, played the piano in her youth, but had to quit due to the war. She came back to it later in her life. Moving with her family to Poland to escape the German occupation of Austria, she ended up a Holocaust survivor, returning to Austria where she met Delia's father, and moved with him to Israel, where she worked as a high school French teacher. Her cousin was a well-known pianist in Austria and often played live for the Austrian radio stations *(then they didn't bring in the recordings, it was live sessions)*, but became sick during the war and had to quit playing. This cousin is most likely the reason Delia's parents wanted Delia to play the piano *(she was quite a good pianist… and she couldn't continue working as a pianist I think that's maybe the way they were thinking about the piano. And they bought a piano).*

Two major decisions were made early on by Delia's parents with respect to Delia's future musical life. First, with Delia's fast progress in her 2nd grade group recorder lessons and her recorder teachers' recommendation to take on a more serious instrument *(the teachers there said that I'm very musical and very talented, and that I have to study something more serious)*, her parents decided she will play the piano. With the new German piano her parents bought, Delia started her piano lessons with a teacher who lived nearby when she was eight, the same year she began music theory classes at a local conservatory. Second, approaching high school age, Delia's parents debated the idea of her attending the Thelma Yellin High School of Arts to study music, but eventually turned it down *(it was not considered a good school for other academic points)* in favor of a regular high school, completing her musical education in the afternoons.

Being self-disciplined, Delia's parents needed to remind her of piano practice only occasionally *(sometime is it much more appealing to go outside and play with friends… I don't remember a time that I said, "Ok I don't want to study anymore,").* They used to listen to her playing, and encouraged her to participate in student recitals *(always complemented me).* Delia's musical talent was appreciated by others who heard her playing *(every time I played in a concert, and that all the people said that I'm very talented, and much more than the average),* including judges of her playing music of Bartok, at one of the student competitions *(they were very, very, very impressed)*.

Delia loved playing outdoors and was a member of the Israeli Scouts organization, travelling with them on numerous trips and serving as a guidance counselor *(quite a regular child).* In high school, Delia chose the mathematical sciences track because she enjoyed and was good at both mathematics and physics *(I also was very, very good in mathematics).* With music already part of Delia's life, it became more serious during her high school freshman year, when she switched from her childhood piano teacher *(she brought me to a certain level, that from there she couldn't give me any more)* to Prof. Edith Kraus whom Delia's neighbor recommended as he knew her from the Terezin concentration camp. If not for Edith, who also prepared Delia for her performance entrance exams to the music academy, Delia would not have considered studying music at the university level *(this was I think my really jump in my musical abilities… she really taught me how to analyze a piece, and to put you know the small stuff about the nuance and the tune and what to pay attention and everything… she in fact gave me the, the confidence)*.

Debating her future academic plans following high school, Delia realized that if she intends to pursue music academically, she cannot afford joining the required army service *(two years in the army will ruin all my musical life* which *happens to a lot of musicians in Israel).* She also felt fortunate to be able to transition with Edith beyond high school into the music academy *(usually all of her students were from the Academy of Music, but she accepted me when I was 15 or 16,…*

so I decided not to let the music go). At the same time, Delia was good at math *(even got 100 in my exams, and matriculation)*, liked it, and recognized the practical benefits of studying mathematical sciences over music *(it was much wiser to go study mathematics, physics, and science then go and study music).* Following these considerations, she deferred her military service at the Israeli Defense Forces (IDF), an option available to academically gifted high school students, and enrolled at Tel-Aviv University for her B.A. studying both disciplines in parallel *(I said, if I was accepted to music, so why not to, to, to do them both. That was my thinking).* This time, although Delia's parents encouraged her to study both subjects in parallel, it was her sole decision.

Juggling between music and computer science *(those disconnected subjects)* was not easy *(they were both… on the other side on the university, and I think I did Marathon running from the two corners).* As there was no separate computer-science department at that time, and computer science was a new field, Delia studied mathematics with a specialization in computer science. She took calculus and programming language courses, enjoying the procedural aspect of writing programs *(I quite liked the computers… it was very procedural thinking unlike music is. It's something that you do step by step, it has a logic inside. You can't do one thing before you do other. It's an algorithmic procedure).* Delia favorably recalls her university calculus teacher, whose class was used to filter out weak students *(I think he was a good teacher. He explained the material quite well),* who happened to be also her daughter's calculus teacher. She also admired her high school physics teacher who was an exceptional instructor and a nice person *(he took the teaching very seriously, and was very disappointed when somebody didn't succeed… and liked me very much… he remembered me* *many years after I completed high school… and he always told my parents that I'm so talented at mathematics. I think I was one of his favorite students).*

Continuing debating her career choices after completing her B.A. in music and math/computer-science, Delia chose computer science as her career *(where there is room for many people to be involved, while in music if you really want to be a good performer there is not a place for many, usually only few get to the top)*. She rejected music as her potential career, eliminating the music teacher path, which most music students become, because teaching bored her *(I tried to teach eh, some children piano… most of the children that came, their parents sent them, and they really didn't have much involvement in music).* As for becoming a professional performer, she was not interested in the hard and focused work involved *(you really have to be engaged to this subject in order to be a good performer, and not to be spread to a lot of subjects like I am… it demands from me too much and I didn't want to… to be so eh, so focused).* She also becomes nervous before and during performances *(I a lot of time prefer not to perform and not to stand in this situation that I am shaking),* and being shy she lacks the public relations skills required for a performer.

With a decision to keep music as an avocation, Delia began to fulfill her military service, working at an experimental, computerized department designed for managing the needs of all IDF officers. While serving in the military she married[81] her husband. Released from military service due to her subsequent pregnancy and aware of the difficulty for a pregnant woman to obtain a job in the civilian workplace, Delia continued for her Master's degree in Information Systems *(which was of course related to computer science)* at the Tel-Aviv University business school. There she worked on a music project, developing a software program that composed

[81] In Israel, a female who defers her military service for academic studies, is not exempt from her service unless she bears a child.

harmonies in Palestrina[82] style from music harmony rules, all written in the Pascal programming language *(I decided to try to put those rules into computer rules, and that the computer, I will give him a theme and he will continue this theme, and generate music in this style).* Although this project did not relate specifically to information systems, she chose this project because her advisor and mentor, Professor Moshe Ben Bassat, an expert in AI and expert systems, was interested in her project. The committee members at her final presentation, which included a demonstration of her computer program along with her own playing, readily approved of her presentation *(they were fascinated because it's, it really was an exceptional subject).*

When Delia was hired as the first recruit in her mentor's startup expert systems company IET[83] (Intelligent Electronics), she worked part-time so that she could raise her children. She worked at IET for 14 years on defense projects and on commercial ones, like the iTest project for fault detection in electronic cars, guiding technicians in identifying the faulty component in the circuit using a statistical-based algorithm. She also worked on another project, W6 (the Who, When, What, Where, Why, How), scheduling service technicians by optimizing the technician's route and customer's wait time, with Delia designing the optimization algorithms *(they still see my name in the system… in the code).*

Around the year 2000, Delia decided to join her husband in starting up their own company in product management *(he will do the business stuff and I will do the programming).* However, with the 2000 information-technology bubble collapse, their plan was discontinued and Delia joined Ingeneo, where she designed mathematical and statistical algorithms *(an engine that gives you the next best offer regarding the customer profile… and*

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[82] Palestrina is an Italian Renaissance composer of sacred music and the best-known 16th-century representative of the Roman School of musical composition. The "Palestrina style" serves as a basis for college Renaissance counterpoint classes.

[83] IET was later known as Click Software, which exists to date.

obviously it learns from customer reactions… to the offer), still working there to date following several mergers and acquisitions.

While working, Delia became interested once again in a hobby, this time biology (*I didn't think about it as a career, I was interested in this subject and decided to study biology… I did it for, for my fun… I think the cell, eh, the reactions in the cell… the system is fascinating).* Knowing she will gain knowledge only if she will formally study the subject and prepare for exams, Delia dropped to part-time at work and enrolled at the Biology department of Tel-Aviv University in 2003, being one of their older students (*if I will go next time to study something, and I believe I will as I know myself,* (laughs) *I will do it now without a degree… because this commitment is also the bad side).* Since the company she worked for went through a merger, she contemplated continuing for her Master's in Bioinformatics,[84] but soon gave up, realizing that the department prefers younger students, and rejoined the newly merged Ingeneo[85] to complete the project she started.

Delia did not have the time to practice much of the piano while working (*I was working, and I had small children, and to put also music into it. I didn't have eh, eh time for it)*, although she always attended concerts and music festivals *(waiting for the jazz festival in Eilat in August).* When her children grew up and a music conservatory opened near her home in the town of Herzelia, she wanted to come back to practicing music *(so I found a time for myself, and I decided this is a good eh, idea to come back to the music, to music).* Delia decided to pick up the clarinet, perceiving it as easy and less demanding than the piano, and wanting to try something new rather than focus on one thing *(I like to, all the time study new,*

[84] Bioinformatics is the application of computer science and information technology to biology and medicine.

[85] Ingeneo merged with ESI (Essence Security International) and was then acquired by SAP, a German multinational software corporation that makes enterprise software to manage business operations and customer relations.

new things that interest me, and clarinet is new spirit, new thing, so *it was exciting)*. After two years of clarinet lessons Delia joined, as a clarinetist, a group of amateur, adult players made up of two flutists, one violinist, three clarinet players, one saxophone player, one horn player, and a pianist. Occasionally, Delia would play the piano part, when the pianist plays the tambourine. The group plays classical and popular music *(we are playing a quartet of Mozart… songs of Kurt Weill for instance. So it's a mix… we took six or seven songs of the Beatles and made special arrangements… last year we played something from Bach),* typically performing in the conservatory but sometimes in other venues like nursing homes. As Delia did not perform much in her youth as a pianist, except for the required conservatory and Music Academy recitals and exams, now, with her conservatory ensemble, she has been performing in public concerts for over six years.

While preferring to work on her computer-science projects by herself *(I get a task and I usually prefer to do it alone),* Delia likes to be part of a music ensemble for its social aspect *(it is much more fun I think, the harmony… some kind of em, social event)* and for the security it provides *(in a group, you know, other people sometimes cover on your mistakes or, so it makes you feel more secured. I really don't like performing individually).* Being a good sight- reader *(I can play quite easily from first reading, if the technical level is simple enough*), makes Delia's life easy to participate in ensembles without practicing much in between rehearsals (see Figure 6).

Figure 6: Delia (fourth to the right, holding down her clarinet) with her music group, Annual performance (Ha-Cochav Ha-Shmini youth club, Herzelia, Israel).

Practicing her instruments has always been Delia's weak side. As a student at the music academy she did not practice more than five hours per week *(Edith said, "Delia is playing only on Monday and Sunday"),* while her friends practiced four hours per day. For Delia, practicing five hours a day, as professionals do, would have meant missing a big part of life. As a computer scientist she does manage to socialize during the work day, while as a professional pianist she would have been isolated socially *(individually sit on the chair and nobody else is around you… it's a lot of dedication… you have to put in a lot of energy).* Currently, as the clarinetist in her conservatory group, she practices only during group rehearsals twice a week and not at home *(I'm practicing from one meeting to another… I miss here and there some notes, but it's quite ok… I don't think that others are practicing more than I do, so and from rehearsal to rehearsal we improve).*

When working on her computer-science projects, Delia is not thinking of music *(I don't think much about my playing… usually I'm quite concentrating in what I'm doing),* and vice versa, while playing music she does not think about work.

It does not come spontaneously for Delia to express whether music playing may have informed her work as a computer scientist *(maybe it's true, I don't know. It's a fact that I'm good in both subjects, but does it influence each other I don't know… actually I don't think about, maybe unconsciously it does influence one another, but consciously no).* On second thought, she observes some relationships. First, she feels that playing a musical piece is like architecting a computer system *(it's more maybe like the architecture stuff that you find, the main tune, the harmony, you looking for the dynamics, eh phrases, etcetera, it's more of the high level in the programming).* Second, she finds an analogy between practicing a piece and debugging a program, although practicing is accomplished in a more repetitive fashion *(I try to play it slowly and to, to play it very slowly, and then to practice it several times until I feel confident with it, and then to make it faster),* while narrowing in on a bug may be more linear.

A proficient programmer and systems architect *(to take the project and put it into modules and connections between modules)*, Delia is especially skillful at system analysis *(I'm a very good analyzer. When there's a problem or a bug I'm–I find that problem quite fast and easily… slowly by slowly with the bug I come to the, to the point where the problem is).* However, Delia lacks some skills useful for her work as a computer scientist, especially in public relations, sales, and document writing *(I don't like it. Sometimes it's very difficult for me to put my thoughts in words. I'm always telling it: to write the program is easier for me than to write about the program).*

Music makes Delia feel good *(good for my soul)* and therefore it makes her feel good at her work too *(if I feel good I think I also, I'm doing good with my–it's only a matter of mind, not that it has a practical connection, but I feel good so I'm doing my job better).* She feels fortunate to be able to engage in two activities as opposed to having only work at her disposal *(I feel good when I do this mixture, not only work, work, work).* In addition, music playing is an activity she does solely for the benefit of herself, regardless of how well she does it *(but there is something that I'm doing for myself, and music is naturally a good, a good thing to do for yourself… I'm at the age that I say, "ok so I don't play like Rubenstein, but I enjoy playing." And this is good enough for me).* Working on a new music repertoire is refreshing for Delia and gives her a lot of satisfaction *(the fact that I'm involved in music and doing something new, is giving me a lot of satisfaction, and even I'm not a professional, I'm not going to be a professional, I know that).*

When she retires, in about two years, Delia hopes to revive her piano playing *(sometimes when I get tired I'm thinking, "oh I should–I would be enjoying myself more if I'm playing something on the piano." I really miss the piano… obviously if I go now and play a tune, a Chopin tune, I will not be able to do so, but simple stuff, oh em, even for our group I can quite easily go back and do it).*

In summary, the main ideas in Delia's story are:

- Good sight-reading skills;
- Studied formally music and computer science in parallel;
- Prefers to be involved with music and computer science, and clarinet and biology, and more things in the future, rather than very focused on just one subject;
- Some career decisions were made by her parents;
- Multi-lingual;
- Combined music and computer science in a project on Baroque music;
- Studies more than one instrument (recorder, piano and clarinet);
- Served in military;
- Initially, finds it difficult to identify how music informs work, but then gradually things started to come out;
- Has a constant desire to learn something new;
- Work complements hobby: likes to work individually at work, but prefers music ensemble;
- Does not like to practice (focus on) music;
- Played piano in youth and started clarinet in adulthood.

D. Sol

Sol was born into the world of a classical music celebrity. His father, a child prodigy in Russia, became a well-known 20th century American pianist and composer who lived to be 108 years old, introducing New-York audiences to non-standard, often radical contemporary music. His mother, from a well-to-do art philanthropic and multi-generational American family in Manhattan, was also a pianist but not on the same level as Sol's father. She worshipped her husband comparing his music to Bach's, and developed ways of working with him, jointly running a music school in Philadelphia and subsequently becoming his scribe *(he would essentially dictate things to her, she was very musical and knew how to take dictation and ah, so they worked together almost all the time that I knew when he was writing, she was sitting at a little card table with the ah, manuscript, he would sort of dictate things to her, he'd make notes himself, scribble little notes himself so that he knew, just to help him remember what he was doing, but then they would fill it out together, and ya she was able to offer comments and advice and so forth)*. This composer/scribe relationship would drive Sol later in his life to develop his Mockingbird[86] computerized music editor to assist composers in writing their music.

Both nurture and nature play an important role in Sol's musical life. As soon as Sol was born, his father began leading a more sedate life with less travelling, making it possible for Sol to listen to his father's practice *(I loved, I loved music from the outset, I grew up listening to practicing*). While playing outdoors at their New Hampshire summer house, Sol used to listen to the Debussy (1862-1918), Beethoven, and Bach that poured out of his father's studio. Sol believes that music is part of his genetic makeup *(I seemed to have the music gene*

[86] Mockingbird was the first interactive, computer-based music-score editor, developed at Xerox PARC, CA.

and ah, sooner or later that was bound to manifest itself… that's just how I'm built apparently). Sol's daughter, too, plays in the church and is very musical. She plays lots of Ravel (1875-1937) pieces that are very difficult *(I knew that my playing was part of what had caused her to be interested, she obviously was very talented musically*). A popular movie about Chopin[87] (1810-1849) sparked piano performance as an important dimension during Sol's childhood. This spark was further ignited during his teenage years *(I realized that this stuff had been soaking through to me through my ears for many years* and *that young ladies gathered around when someone played the piano).* Sol became interested in playing the piano *(I suddenly took it on as a real job… it was a self-perpetuating kind of thing, the more I got into it, the more enthusiastic I became and while playing).*

Sol insisted on being a self-learner and rejected his parents' offer to take piano lessons or study with his father, believing he was too young for piano instruction and that it was *sissy stuff.* Sol's father never corrected Sol's piano playing as he was too busy in his own world– something Sol did not resent. However, Sol did comment on his oldest daughter's playing while practicing and she did not like it *(I would be upstairs and she'd be playing some piece that she was learning that I've never heard before, and I would shout down at her, "No, no! That's got to be a sharp there.").* Later on, Sol also became a self-made computer scientist, never studying it formally (there were no computer-science programs available in universities back in 1950s*).*

Sol's listening and memory skills spared Sol from having to read music. He used to play a lot of Chopin, some Beethoven and Ravel, learning by listening to his father's playing *(very few people have the kind of upbringing that I had. I hardly had to read the notes back when I was learning some of the Chopin pieces for example. I knew exactly what they sounded like and looking at the music, very quickly… I learned it very, very quickly).* Consequently, Sol

[87] The 1945 movie *A Song to Remember*.

did not develop sight-reading skills nor did he explore many of the theoretical aspects of piano playing in youth. He practiced many hours, developing his own practice routines identical to traditional routines, and was careful to practice while his parents weren't at home to give them some relief from music, never playing on his father's piano which was on the second floor, facing the mountain.

Although Sol's father did not compliment Sol directly, Sol overheard him occasionally commending his playing and his practicing routines, talking to his mother about a Chopin piece in particular, "*look, look he's figured out all by himself how to do this."* His parents enjoyed his musicality and interest in music *(subtly managing to pass along the encouragement that they noticed… they were delighted that I was interested in music and understood music).*

Although Sol rejected people's ideas for him to become a musician like his father, he briefly considered music as his career in the middle of his college years *(I wanted to be a musician, I wanted to be a music major)*. When Sol's parents realized his interest in music as a career, they tried to discourage him even though they were happy all along about his playing *(it appalled them because they thought that was a hell of a way to make a living…and this horrified my parents, ah because they knew what, you know, that it wasn't the most thrilling kind of life actually, and they discouraged me, and I wasn't easily discouraged)*. First, Sol's father reasoned with Sol about the rare likelihood of becoming a top pianist *(very few people really could rise to the top… and that if you were a second or third rate pianist that it was a terrible life)*. Second, he portrayed performers as second class musicians *(the only real reason for going into music as a career was if you had something to say, if you were a composer with, with some real thing that needed to be put down).* Finally, Sol's father minimized music performers *(performing is just athletic, like a, like being a gymnast or being, you know, an acrobat of some sort),* and elevated composers *(something that's really important to say you know, and then, then you have an excuse for living that kind of life)*. Sol feels he grew up in an interesting family *(my dad was not a limited intellectually the way many musicians are by the demands of practicing, Ah he was a tremendous reader, had a large library, and ah, saw to our education).*

In addition to his father's pleas, Sol had his own reservations. He felt he was not cut out to be a composer and that like Wagner's (1813-1883) son who had a tough road with his father, it is too much of a burden for a son to deal with, given his father's success in the same field. Second, he believed he was not equipped with the necessary foundations in music to pursue it academically *(but when I really understood how much work was going to be involved in catching up–I was by then, what, 17 or 18 years old–and I hadn't really practiced, I hadn't learned a lot of the disciplines that one needs to be a musician).* In addition, Sol gets nervous during public piano performances *(since my memory of the piece is in my hands, if I make the slightest slip, you know, and get off, I can't get back on track. So, so for me, public performing has never been possible)*. Although his father also gets very nervous before performances, he, unlike Sol, could discipline himself *(you just have to get relaxed and get involved in the music and then play).* Although not fit to perform in public, Sol did perform in intimate settings such as when a friend's wife was dying *(for that reason I was able to bring myself to ah, actually play for a group of people).*

As an undergraduate, Sol had a second passing thought of considering music performance as his career but eventually gave in. He never regretted his decision and encountered at least two situations that confirmed his earlier intuition of not choosing music as his professional career. The first time was while on a business trip, listening to a once famous pianist perform the Schuman (1810-1856) piano concerto against a tape recording of the orchestra part in a Café in Prague *(he was playing, as people, people were having their supper, and ah, there sitting on the piano was a picture, a photograph of the one night when he had actually performed the Schuman concerto with the Netherlands Philharmonic, and it was clearly the high point of this life that one evening, cause he was clearly not a great pianist, he was a reasonable pianist, but he had been condemned ever after to basically playing in a café).* At that moment Sol was grateful he followed his father's advice *(I could have ended up similarly in a second rate position, whereas in fact, at that time I was riding quite high, we had just built the first part of the internet, and you know, were receiving a certain amount of acclaim internationally, and something that would never have happened if I had gone into music)*.

In another situation Sol encountered a music professor whose father, a worshipper of Sol's father, made him become a pianist rather than letting him pursue his desired career in medicine. This professor described his life as a pianist as agonizing because of excessive traveling, only getting to substitute for first-rate pianists, and finding himself often contemplating becoming a doctor even at the late age of fifty. Sol has been content with his decision not to pursue music as his career, as he has met many musicians throughout his life *(few of them, you know, really enjoy the life, not just the music but the life that goes with it).*

Sol's love of the outdoors naturally paved the way for him to enroll as a geology major at Harvard University, which offered a mountaineering club. A mountain climbing expedition acquainted Sol with a programmer from Lincoln Labs at MIT who worked on the

Whirlwind[88] computer for oil exploration. He introduced Sol to computer programming at the time when Sol was completely ignorant of computers *(I didn't even know the word 'computer'),* though Sol intuitively felt their potential use *(some kind of device obviously can do what we're doing by hand).*

Sol was fascinated by the programming tutorial he received from his pal and by their joint trip to MIT to see the Whirlwind computer, occupying rooms full of equipment *(mostly I was amazed at the cleverness of it, you know, the ingenuity that went into, and so I was interested "how did the damn thing work?")*.

During his doctoral studies in geology, first at Berkeley and then at Harvard, Sol decided to quit graduate school *(I wasn't really cut out to be a geologist)*, working in the meantime at Harvard with a geophysicist for a couple of years. Sol then joined the Gulf oil company, and he accidentally reconnected with his former mountain climbing pal, as he noticed in the company headquarters' parking lot the unusual scene of a climbing rope sticking out from a parked car. Thanks to this encounter, Sol joined Lincoln Labs in 1954 as a computer scientist, *(that was what I really wanted to do… and so from then on I really was, was happily away with a career in computing).* Equipped with his prior mentoring from his pal, self-learning ability, and math and physics Ph.D. coursework, Sol was able to join their missiles tracking project and skip their training course. After developing an antipathy toward military work and following a split in his group, Sol decided to stay with the research team, building the advanced TX-2 computer that became the world's first personal computer. The head of the TX-2 group became another serious mentor for Sol in the field of computers and started an effort to build the breakthrough LINC (Laboratory INstrument Computer) that

[88] The Whirlwind computer, manufactured around 1953, was the first digital computer capable of displaying real time text and graphics on a video terminal. It was also the first to have core memory for Read Access Memory (RAM).

could display real time data to be used in the medical field *(and that just absolutely blew me away, I thought that's the most exciting thing I ever heard.. cause that was exactly the thing I wanted to do)*. Sol's group, under the sponsorship of the National Institute of Health (NIH) rolled out twenty such computers, training doctors in various disciplines about their use and programming *(I've never worked so hard in my life… it was quite a dramatic affair. Ya it was the high point of life for a good many people I think).* Moving out from Lincoln labs to look for sponsors for the project, Sol and part of his team landed in Washington University, St. Louis, trying to spark interest in additional domains.

After three successful years in St. Louis, Sol returned to Boston, though brokenhearted as he loved the people he worked with. Declining a research offer from Harvard, he began working at BBN in 1967 while teaching a course on hardware design, a machine language programming course, and a graduate seminar at Harvard. Called to respond to a Request for Proposal (RFP) from the Defense Advanced Research Projects Agency (DARPA), Sol and his team won the bid to build the ARPANET[89] network *(that was basically the beginning of the internet there, so actually we were ahead of everybody else. So we were quite happy and got a lot of good press as a result of that)*. Sol was in charge of the hardware part of the design, and worked closely with the programmers *(who were, you know, of course personal friends by then)*, and with the team's chief software engineer, who was also a rock climber and later became a computer games pioneer. After Sol left BBN in 1976, he went to work at Xerox PARC where he developed the Mockingbird music editor (see Figure 7).

[89] Advanced Research Projects Agency NETwork. The ARPANET was the first operational packet switching network, the first network to implement TCP/IP, and the predecessor of what was to become the Internet.

Figure 7: Sol and his collaborator from Xerox PARC, next to the Mockingbird system (1980).

Sol attributes much of his success in the field of computer science to his mentors, some of whom were his climbing pals and personal friends. Becoming a self-made, savvy computer scientist, Sol never expressed an interest in formally studying computer science. Moreover, by the time computer-science departments existed he could teach rather than study that discipline.

Due to his workload and raising a family, Sol's piano practice while at Lincoln Labs and BBN became minimal. That, however, did not stop him from asking his manager at Lincoln Labs to bring a piano to his office, knowing that another person at Lincoln Labs had one, and agreeing to practice only during lunchtime and non-work hours *(I primed all the guards to expect this… when the piano actually arrived, one of the guards called me and said, "there's a man here who claims he has a piano for you" and disbelief in his voice… and I went tearing down and I found the guy who was delivering the piano had arrived at the back door,* *the delivery door of this super secret Lincoln laboratory …).* Sol enjoyed practicing at lunchtime while people came to listen *(I never got any complaints and ah, people said nice things about it).*

In addition to integrating his piano practice with his computer-science work environment, Sol combined computers and music in numerous other ways. Known in the computer-science circles as a computer scientist with interests in music *(that would've appeared to be my sort of central interest),* Sol was offered in 1967-1968 by Ivan Sutherland,[90] a former colleague and DARPA executive who was teaching at Harvard, to work on a research project that combines music and computers, but declined *(he knew that I was interested in computers and music, I had made a proposal for a machine that would be an assistant for a composer).* Then, when at Lincoln Labs, Sol attempted to develop a program that transfers music played on his office piano to his TX-2 office computer, which had an analog-to-digital converter, to be analyzed and printed. That turned out to be a more complicated problem than he originally envisioned as Sol began to realize the complexity of music *(I understood how complicated even a single note is on a piano… I realized that your brain is doing a tremendous amount of work even on a single note, let alone on the structure of the music itself when there are bunches of notes. So I soon realized that was an impossible task and I tried to analyze the sound waves, and so I started exploring underneath the keyboard to see if I could put something to detect when the keys were pressed, and even then, you know, I came to understand later how naïve that was because there's a lot more that goes into the structure of music than just when notes are put down. Ah, you know, there's how long the notes are, what goes with what and that sort of thing. And so I eventually realized it was a hopeless task, a*

[90] Born in 1938, Ivan Sutherland is an American computer scientist and Internet pioneer. He received the Turing Award from the Association for Computing Machinery (ACM) in 1988 for the invention of Sketchpad, an early predecessor to the sort of graphical user interface that has become ubiquitous in personal computers.

lot of people had tried to build things like that, and that's an AI problem roughly equivalent to the speech problem, trying to understand spoken speech).

The fourth occurrence of synthesizing his interests in the two disciplines of music and computers was at Xerox PARC where Sol took it upon himself to design a computerized, interactive music editor–the Mockingbird *(I really have two fairly separate lives really, the music and the computing, although they came together when I, when I was working on the music software at Xerox PARC… for the first time I really managed to bring my understanding of both music and ah, and computers, what computers can do very closely).* The Mockingbird was not as complicated as his initial project at Lincoln labs *(required a person to go along and ah, and put structure down on top of the raw material that we could gather and convert it essentially from a piano role like structure into actual music score… the person who's writing the piece, knows what the important pieces are, what is the melodic line, which chords go together, what things need to be beamed together).*

It was Sol's memories of his father's struggles, frustrations, and inefficiencies that motivated Sol to develop the Mockingbird *(he could play large segments of a piece just rambling on, and ah then it'd be time to write it down and he'd go back to–he couldn't remember where he started or how he got there).* At some point his father tried to be helped by the tape recorder but found that rewinding the tape was hopeless. Combined with his past experience of developing computers that changed the lives of professionals like doctors, Sol was determined to help his father and composers alike *(I thought to myself, "there must be some way in which computers can help in this process," because there ought to be some equivalent to a music typewriter).*

When Sol first described his ideas of a music editor, most people did not understand what he was trying to do, except for experts like Don Knuth[91] who is also interested in music. Composers Samuel Barber (1910-1981), Aaron Copland (1900-1990), and Leonard Bernstein (1918-1990) told Sol that indeed they are being helped by their piano playing while composing.

The Mockingbird also helps musicians understand the structure of their music as it enables them to view the written notation of the music being composed *(I studied various piano scores and realized that the notation system highlighted the structures and that that's what, that's what it was all about, that it's a 'what goes-with-what' is how I put it, things that are connected both laterally and vertically, ah that recognizing that those structures are the important ones in music, ah in the music notation system, and that* <u>*that*</u> *was the structure which the person had to lay on, and that once you had laid that structure on, then the computer can provide further help).* Developing the Mockingbird required Sol to view music in a structured fashion *(it suddenly became necessary to look at the thing–look at music structured, especially piano music analytically and realize that because the piano is an instrument that can play many notes at the same time, that in fact what it's doing is emulating a orchestra or a, some group of musicians, and that each one has, or at least temporarily got a place just as in listening to a quartet, You know, the second violin sometimes plays, sometimes doesn't play, and you know picks up ideas, it's got its own part and ah piano music really consists of multiple parts very often, and ah recognizing that structure was very important because ah, it was part of how we built the system to let the user superimpose that structure on the, on the sort of raw materials, and when I described*

[91] Donald Ervin Knuth (born in 1938), known as the "father" of analysis of algorithms, is a computer scientist and Professor Emeritus at Stanford University, and the author of the seminal multi-volume work *The Art of Computer Programming*.

that to some musicians, it was a revelation, they hadn't thought of it that way before. So ya– but I don't think it had anything to do with my playing, because my playing as I say has always been very intuitive and I feel the thing even if I, even if it's completely unconscious).

By displaying the composed music in a written fashion, the Mockingbird also helps composers better remember their music *(it imprints it more solidly in your head and also your fingers probably help to remember).*

Music flows in Sol's head in the background all the time *(it's a faint form of hearing the actual music*), which Sol believes is part of his genetic makeup. With this faint background music he can still focus on his work *(listening to music in your head is a sort of subliminal kind of thing… It doesn't seem to take place in the same part of the machinery where your conscious thinking takes place…my consciousness is focused on what I'm saying or what I'm hearing you know, the thing that I'm doing).* Sol's wife, too, hears music in the background and when they both return from a concert at night they will be kept awake *(because the music will be going around in our heads and we won't be able to turn it off).* When Sol plays the piano he is just focused on that and is not thinking of work or anything else**.**

Sol's weak sight-reading skills prevented him from playing in chamber music settings with other people and made piano solely a personal endeavor for Sol *(I've regretted that because I see how much pleasure people get from playing together, and I envy that, and I've tried to practice my reading).* However, in the past 10 years, Sol and his wife have been engaged in social music endeavors, running a chamber music concert series out of their home *(that's taken a good deal of my time, just organizing that and arranging that and dealing with other musicians).* Unlike piano playing, work has been a social endeavor for Sol, as he chose his projects mostly based on the people involved, not on their topic *(Um, I was willing* *to ah, I was willing to just do whatever needed doing in a particular group because the people seemed like they were fun to work with).*

He dislikes contemporary music because it is constructed artificially rather than being triggered by a good melody *(I talked to one composer, who shall remain nameless, who said, "oh ya well I put down a rhythmic structure that I know that I want and then I fill in the notes later." Well you know, hell, that's not my idea of how music is then, and his music sounds like that, ah you know, sounds constructed, somewhat artificially).*

At work Sol is analytical and in his piano playing he is intuitive. As an analytical person at work, he is always curious as to how things work *(whether it's um, (laughs*) *we're just having solar panels installed on our place for example… I've participated in the design of what they're doing and wanted to know it each step of the way exactly how it's going to work*). He likes to go as deep a level as his potential enables him to understand things, also in disciplines which are not in his experience like circuit design *(I think I'm naturally a pretty inquisitive person, and I have a desire to, a strong desire to understand how things work, and ah to the extent of my abilities).* When Sol works he turns his analytical part on and switches off the appreciative part of the listener in him. However, in a recent quartet performance of a piece Sol knows well, Sol found himself in a rare situation analyzing the piece *(watched exactly how the composer had put it together, you know, and how they appeared and reappeared in different guises),* which was an unusual activity for Sol, *(not one that I usually indulge in, it sort of trying to understand).* With piano playing, Sol works mostly intuitively *(you're dealing here with a very intuitive guy… I don't think I'm an analytic kind of person especially in regard to music, I operate just very intuitively).* Sol is also logical at work *(when I face a problem, I do think logically about it).* Same as with music, Sol believes that computers and programming come naturally to him *(I just had a native talent for logic and for, for programming. Took to it like a duck to water).* His logical thinking helped him get a computer-science teaching position at Harvard without having a formal computer-science degree.

When playing piano, Sol uses his memory and tactile senses *(my hands remember as much as my ears, my ears remember, but ah, but intellectually ah you know, if I put my hands up on the piano I know exactly how it's going to sound. Ah so I think a lot of my memory is in the physical part of my playing as well, although you know, that helps with the, if I'm going to play a particular piece).* At work he does not rely on memory but rather uses deeper understanding, analysis, and logic *(and once you understand something, if you don't remember it you can reconstruct it).*

Practicing piano relieves his mental tension, which in turn triggers inventiveness *(in my experience a lot of inventiveness does come when you sort of relax the mind, and deflect back the tension).* When Sol, who is a bad sleeper, wakes up at night and has a hard time getting back to sleep, he sometimes practices the piano which helps him relax by deflecting his attention from waiting for an inspiration to strike to go back to bad**.** The effect music practice has on Sol's inventiveness is analogous to brainstorming with other people, like when exchanging ideas with his wife.

Sol claims that his quality of life without piano playing would have been much worse. It has helped sustain Sol during unhappy times and hypothetically would also help him survive possible hardships in the future. Nowadays it is music in general that adds to his happiness, not necessarily music playing because he plays less. When he used to play, he enjoyed practicing *(I still enjoy practicing, I have little time for it these days, we have other things* *that we like to do too)*. Up to three or four years ago, Sol did not have long periods in which he did not practice the piano, except for periods of time-consuming work projects. However, recently, his practice has been more episodic as his memory has been degrading, discouraging him from learning new pieces *(it's, it's such a struggle it's hardly worthwhile, and ah so that's damped my enthusiasm).* His and his wife's home concert-series make up for his lack of recent piano playing. Similarly, not presently engaged in computer-science work per se, Sol has been heavily involved with his wife since 2000 in encouraging and educating people about the implications of computer work through the Computer Professionals for Social Responsibility organization he and his wife co-founded in 1983. In fact, in 1994, when invited to speak publicly in a gathering of internet pioneers, Sol had foreseen the internet becoming a vehicle for democracy.

As with music, computer science saved Sol's life as his early geophysicist work was terribly dull for him *(I thought, "My god, the fun is all over, now it's all drudgery from now on." and ah that, that certainly lasted, that attitude and view of the world, lasted for whatever it was, a couple of years until I got into the computer field, and I thought, "Wow! They're actually paying me to do this. I can't believe it").* As he describes in his book *Computing In The Middle Ages: A View From The Trenches 1955-1983*, life as a computer scientist was rewarding for Sol, he was good at it, and managed to work with the big names on life-changing projects in the industry, like the first router and the first part of the internet at the right time *(I was very fortunate in the particular choices I made along the way about which groups to work with and who to work with).*

In summary, the main ideas in Sol's story are:

- Very musical household;
- Inspired to play the piano by a Chopin movie;

- Self motivated to play;
- Did not get formal education in neither music or computer science;
- Combined music and computer science in innovative ways (initially prompted by personal causes);
- Both nurture and nature (musically talented) involved in music development;
- Computer-science work was rewarding (participated in breakthrough innovations);
- Went through several career turning points (started as geologist);
- Risk taker;
- Courageous;
- Self learner in both music and computer science;
- Without piano, life would have been significantly reduced;
- Has several favorable mentors in computer science;
- Attributes much of his success in computer science to his mentors;
- Has good memory skills in music;
- Poor sight-reading skills.

E. Miro

Music, mechanics, math, sciences, and electronics became important for Miro before he even started to talk, as he was fascinated by record players and watching records change while listening *(you could put a stack of six LPs, which is great because it would keep me occupied for three hours).* At home, in Schenectady, New York, Miro loved to listen to his father's small but impressive record collection, especially to Jazz musician Woody Herman, the only record that made him stop crying as a baby, and to classical music *(I couldn't decide whether my favorite composer was Beethoven or Tchaikovsky)*. He frequently visited his neighbor, an electrical engineer at GE,[92] where he would listen to Sen-Sans' (1835-1921) organ symphony and Cesar Franck's (1822-1890) symphony, while solving Martin Gardner's mathematical puzzles from his neighbor's large collection of *Scientific American* magazines *(I was more mathematically advanced than, than they were at school).* In addition to his early musical, mechanical, mathematical, and scientific interests, animals have always been a true love of Miro's (*I love animals … I've got to have pets. I've got to have a cat or a dog or something).*

[92] The company General Electric.

At age 12, Miro became fascinated with his father's occupation as an accounting systems designer (nowadays called software architect) at GE and started reading about computers, even creating a Touring machine[93] from paper *(I took paper, cut them into strips, taped them together, and marked them off as squares…).* Miro's father, from a Welsh family who settled in Colorado, used to practice Rachmaninoff's (1873-1943) Prelude in C sharp minor *(he just practiced and practiced and practiced until he could play it*), trying to follow the repertoire of his older brother who was an aerospace engineer and amateur pianist. Miro's mother, from upstate New York, who met Miro's father at GE where she inspected servomotors,[94] played the fiddle, and his brother is presently a trustee of the New Hampshire Symphony *(it wasn't a particularly musical family)*

At age six, Miro started piano lessons, and a year later, when his family moved to Dalton, Massachusetts, he also picked up theory, solfège, and the recorder at the nearby Pittsfield's community music school *(a very very good music school).* In its basement woodshop, Miro with his music classmates made their own recorders out of bamboo *(we had to fit the cork, ee had to shape the cork into a fipple… and we had to make the little hole, with the the little edge for the air, and we had to cut the little holes for the finger holes… and we'd tune them, and then we'd learn to play them, and then at the uh recitals we'd (laughs) play them we'd play duets on them)*. He loved listening to Beethoven's symphonies while following their scores, which he borrowed from the nearby Pittsfield library *(you could only take out eight records at a time, so I'd,* (*laughs) I'd come back with like eight records and eight scores).* He also enjoyed the

[93] A Turing machine is a theoretical device that can be adapted to simulate the logic of any computer algorithm, by manipulating symbols on a strip of tape according to a table of rules. The "Turing" machine was described by Alan Turing in 1936.

[94] A servo motor is an automatic device that uses error-sensing negative feedback to correct the performance of a mechanism.

challenge of sight-reading piano scores he borrowed from that library. After two years of playing the timpani in his high school bands, Miro picked up the sousaphone, a tuba wrapped around the shoulder like a boa constrictor, playing in his school's marching band. He participated in piano ensemble classes playing four hands and two pianos, occasionally even playing with his teachers and classmates, eight hands on two pianos, and in chamber music ensembles accompanying voice students, violinists, and a cellist.

During high school, Miro began attending the Tanglewood[95] summer music institute, with his life story featured in the local paper along with a photo of him playing with the Tanglewood percussion ensemble that included known musicians. During one of these summers in 1966, as he practiced the old piano at the church his grandmother attended in upstate New York, he was offered to play the church organ *(you sit down and you get this tremendous feeling of power. You sit down and you're controlling all this sound… an immensity of music comes out... it's like having an orchestra)* (see right image in Figure 8). After substituting for the chief organist for a couple of summers, Miro became, at age 15 or 16, the chief organist for three years in his own town of Dalton *(playing all the services, and funerals, and weddings)*.

In 1969, at the height of the Vietnam War and students' protests, Miro enrolled at BU as a piano performance student, with a minor in percussion *(I was going to be a musician, it was a little vague as to how it was going to work out),* avoiding top music schools for the low probability of being admitted. He enjoyed BU because of its ties to the Tanglewood institute, its faculty with whom he was familiar from the Tanglewood summer programs, and because he became a member of BU's percussion ensemble.

[95] Tanglewood is a music venue in Western Massachusetts. It is the home of the annual summer Tanglewood Music Festival, Tanglewood Jazz Festival, and the Boston Symphony Orchestra's summer concerts.

Most of Miro's piano teachers did not leave an impact on Miro. With his logical mind and mechanistic view of the piano, Miro often challenged their musical instruction of "crescendo on that note" or getting different tonal colors out of a note *(you say something like that I kind of shut down, because, you know, you basically told me an impossibility… you press it harder, the note's louder. You press it less hard and the note is softer… it's just impossible to play two things).* The only teachers Miro recalls being helpful were his first two piano teachers *(we're kind of on the same wavelength… they got me off to a good start and laid a very good foundation there).* Miro was self-motivated and enjoyed practicing the piano. His parents, who were religious about driving him to all his music programs, didn't need to discipline him to practice except for initially setting a daily practice schedule and occasionally putting him back on a practice track.

Apart from his passion for music, Miro loved watching the science and music programs of the NBC Monitor program and the Adventures in Mathematics program of the Canadian educational channels, which presented university lectures on high level math topics. He experimented with chemistry sets, and learned how to read circuit diagrams and fix TVs and radios from his father.

Although Miro's small, regional high school did not offer a lot of mathematics and science courses, he managed to acquire these subjects by enrolling in the college preparatory track in algebra, geometry, standard math, and science courses. He was attracted to math, fascinated especially by the mathematical theorems about the cardinality of sets *(the idea that there's infinite number of integers,* and *the number of odd integers is the same as the number of all integers),* subsequently becoming interested in the cardinality of computer programs.

Acquiring typing skills in high school enabled Miro to take a typing job at BU, creating the school newspaper and typing students' papers, and helped him obtain summer jobs as a key-punch operator at Computer Oriented Incorporated and at Finserv,[96] which provided data processing services.

During his years as a music student, Miro elected programming language courses like Fortran, enjoying the process of programming to the degree that after graduating in 1973 he went back to work at Finserv as a programmer. Wanting to return to Boston, he was then hired by Data Plus, a small computer consulting firm in Cambridge, Mass., to develop a computer system that helps travel agencies to book tours, enjoying in particular the debugging aspect.

From 1977-1979 Miro enrolled at the newly opened computer-science department of BU's Metropolitan College (MET), designed for people with day jobs. After receiving his Master's degree in Computer Science from BU in 1979, he became interested in more theoretical aspects of computer science *(other things that were going on that were far more interesting, more theoretical... things like compiler construction, and um, mathematical programming).* These new interests brought him to Intermetrics, in Cambridge, to work on a gigantic compiler project. After four years, when the project failed, Miro was hired by Mark of the Unicorn[97] as a music programmer to write a text processor for music notation and later to develop the Performer system that makes a Macintosh computer control a music synthesizer, currently the standardized MIDI interface. The Performer system was subsequently completed and sold as the well known Pro Tools[98] *(about half of it is my own work… this program turned out to be,*

[96] The data processing branch of the American Locomotive Company.

[97] Mark of the Unicorn is a company known for developing the word processor MINCE (Mince Is Not Complete Emacs) and the computer game Mouse Stampede.

[98] Pro Tools is a digital audio workstation platform for Microsoft Windows and Mac operating systems used by professionals throughout the audio industries for recording and editing, in music production, film scoring, film, and television post production.

you know, blew away all competition... immediately became the standard that musicians use… you go to any recording studio and you'll find that they're running Pro Tools).

After leaving Mark of the Unicorn and working for DRI[99] McGraw Hill, Miro joined former DRI employees in a startup business, NewsEdge, developing the user interface for their news aggregation system *(we invented this industry)*, and staying with them for 20 years until 2009, during which they became public and went through some mergers.

Miro's musical life continued while a student at BU and right after, mostly with non-classical music. In 1974, he built an electronic organ out of a $3,000 kit *(it wasn't really hard to do the wood working… I already knew how to use a soldering iron, I had put together small electronic kits),* which he eventually donated to a church in Ghana. With his newly bought Steinway piano he played mostly ragtime, a childhood liking of his that began when he played from the *Black and White Rag* book by George Botsford. With the help of ragtime books and records by Scott Joplin, Miro began accompanying singers at an annual festival in a museum his mother was involved with, and competed in ragtime piano playing contests for professionals and amateurs *(many of the people that come are full-time musicians and entertainers making their living playing ragtime here and there... I went, fifth, fourth, third and second, but never won first*). He participated in the Scott Joplin Festival in Sedalia, Missouri, and became an active ragtime player throughout the rest of the 90s, performing in First Nights in Boston and other cities.

Resuming classical music in the mid 90s, Miro joined the ACMP chamber music group that met at the Phillips Academy in Andover, Mass. He was a good sight-reader and used their get-togethers as his practice for ragtime competitions *(you're thrown off the deep end, and there you are with this Brahms that you never played before... and it's best when, kind of the um, when*

[99] Data Resources Inc.

kind of, when everyone's matched together with the sight-reading ability). Around 2003 Miro also joined BPAA, performing in their monthly soirees and participating in some of their competitions *(I never got beyond the preliminaries… some of the people play at a professional level).*

Through ACMP, Miro was offered by a flutist and former champion bicycle racer, to accompany her in her Carnegie Recital Hall debut, two years in advance *(you say, "ok this opportunity is never going to happen again," I thought to myself…"ok, I've accompanied many people in college and I've done a lot of accompanying, I can do this").* While working, Miro prepared for the recital with his music partner, doing concert tours in New York and New England along with recording their music *(he was using ProTools… so here we come full circle*). They perform together to date.

Miro thinks of music often. However, when he works he focuses on the job at hand *(I'm thinking of programming when I'm programming. I'm thinking of music when I'm* [making] *music).* When the piano and the computer used to be in the same room in his former apartment, he would often, while compiling a computer program, play the piano and then come back to the computer *(switching back and forth between the two keyboards rapidly feels very very weird. because the piano, you've got the wide range, and then you go over to your computer and* [you're] *confined to this little* [keyboard]*).*

Playing music while being employed has not presented a hardship for Miro, except for the need to schedule time off from work far in advance to accommodate performances and competitions. Luckily, Miro's employers were always supportive of his musical endeavors *(most places I've worked actually, people have been supportive of um, things to do in your personal life. People are a lot more enlightened*). Moreover, Miro feels that music helps him become more productive *(you're not going to be fully productive if you don't have some extra outlet).* However, back in the 1980s, Miro's friend, then a pianist in his 50s and 60s known mostly in South America, had to keep his concert career secret while working at Raytheon *(if they knew that he was going someplace playing concerts on his vacations… they would have put a stop to it*).

Miro perceives himself as a cooperative person rather than a competitive one *(I just never liked sports very much at all... I don't really like, um, games where to win, someone else has to lose)*. He likes chamber music because he believes everyone wins. Chamber music encourages Miro to work with people in a team *(you're going to find yourself with people who are better than you, people who are worse than you),* as required in the working world *(you have to cooperate with people all the time).* Miro believes it also hones management skills *(part of the task of a manager is to help a worker who is not working well to become better).*

He never wanted to assume a leadership role as a computer scientist or as a musician *(I never wanted to be a manager… I liked the programming... I never wanted to be a conductor really. Um I wanted to be a musician but I didn't want to be a leader, you know I wanted to be a soloist or a member of a group).* Miro's lack of interest in management might be due to his inefficient decision-making process and lack of confidence in his decisions *(my approach to making a decision is find, you know, all the alternatives and research them thoroughly and present the alternatives to someone who can say, "ok here's all the facts, you decide."... I don't like to make a decision and have it be wrong afterwards or something like that).* He also feels that managers do not get to enjoy the fun part of work.

Miro does not have much of a preference of working individually over team work. He often worked successfully on programming jobs by himself, but joined a team when the work required skills more varied than his, like the graphic design part of his user interface work. Some team situations at work, though, have been bad for Miro, calling for careful organization and supervision *(you've got four programmers and they all want to work on the same part of it, and nobody wants to work on another part of it)*, and similarly, with music, playing solo can be accomplished anytime while chamber music needs to be coordinated. In addition, chamber music provides more opportunities *(I got to play in Carnegie Hall… someone asked me to play in Carnegie Hall. (laughs) So that was an opportunity that as a soloist I would have not even considered)* (see left image in Figure 8).

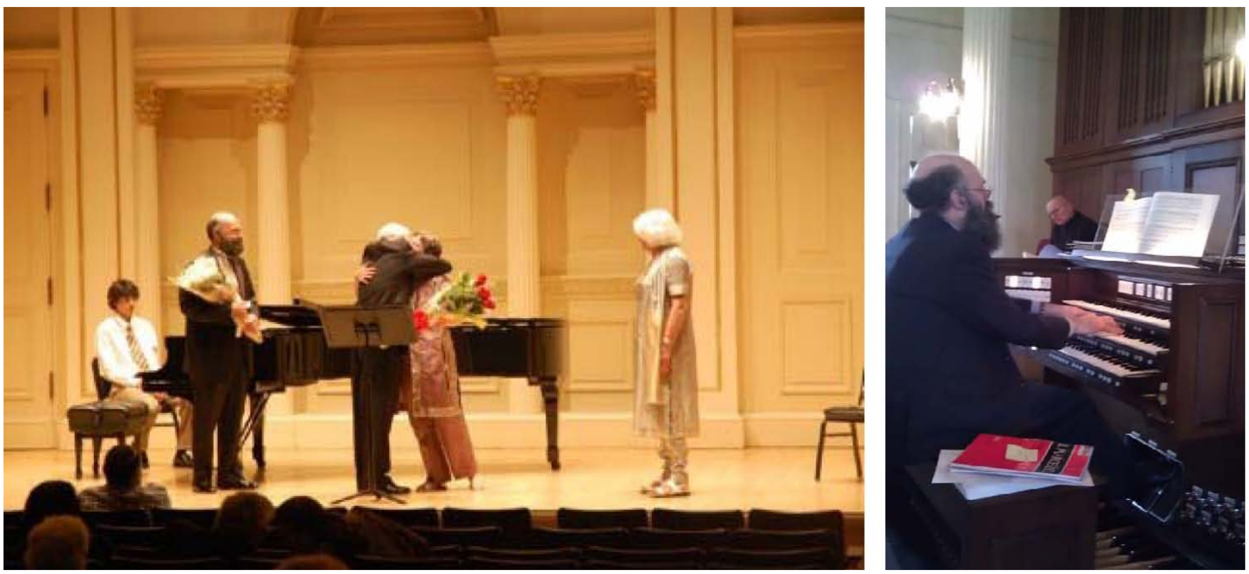

Figure 8: (Left) Miro and flutist perform at Carnegie Hall (June 2008); (Right) Miro at the pipe organ (South Church, Newport, NH).

While performing solo, Miro is nervous *(I didn't really like performing just because of nerves, because of pressure)*, especially when playing from memory which nowadays he avoids. As a young student he did perform from memory, which was also accompanied with anxiety *(worrying about a memory lapse)*. In a recent solo recital at his home, however, performing Beethoven and Debussy for an audience who was not musically savvy *(I called it, "Sullivan Memorial Concert Hall." I named it after a cat I once owned),* he was not nervous *(I knew no* *matter what I did, if I made a mistake they wouldn't know).* With chamber music he is more relaxed as he does not perform by memory.

Music has informed Miro's thinking and work throughout his life. First, he often experienced music and science simultaneously. As a child he used to listen to music while observing the mechanics of sound production, as records moved and changed. He also used to listen to computerized music such as "The Science of Sound" by Bell labs, electronic music by Milton Babbit and Vladimir Ussachevsky (1911-1990), and to the Illiac suite.[100] While a music student at BU, he also took programming courses as well as Greek literature courses *(Greece had the philosophers and the mathematicians. Greece had Pythagoras, had Plato, and it had Archimedes, and Euclid).*

Second, Miro was fortunate to combine his knowledge of music and programming in the workplace, productizing two computerized music systems. He first developed a text processor for music notation *(the language of music is far more complex than, than the letters and words).* He then partook in the development of a Macintosh interface to a music synthesizer, focusing on the usability of the interface by the musician *(I was very much insisting that, ok "to be usable it has to have this, to be usable it has to have that, a musician is going to demand this, a musician is going to demand that… I had some input into the musical editing program. I brought in the Beethoven sonatas and said, "look it's going to have to do 120 eighth notes, it's going to have to do 256 notes).* Apart from the workplace, when obtaining his Master's degree in Computer Science from BU, he programmed a subset of music counterpoint[101] rules he acquired from text

[100] Illiac Suite, composed in 1956 by Lejaren Hiller and Leonard Issacson is considered the first piece of music composed by an electronic computer.

[101] Counterpoint is the relationship between two or more voices that are harmonically interdependent (polyphony), but independent in contour and rhythm. Counterpoint is most commonly present in classical music, and has developed mostly within the Renaissance and Baroque music.

books from his music professor, composer Hugo Norden *(people like Palestrina and Bach had said to themselves, "ok what sounds good, and can we reduce what sounds good to mathematical type rules?").* These rules, for example, control the direction of the movement of parallel voices, prohibiting, for example, the movement of parallel fifths in the same direction, and can be represented mathematically by assigning numbers to the notes of the piano. Miro saw the resemblance between these music counterpoint rules and mathematics, as he represented these rules in a mathematical fashion with a Fortran program *(it explains the rules in a way that is,* you *can almost see the mathematics behind it).* Miro was attracted to his professor's counterpoint textbooks, as they were written in collaboration with an engineer who gave them a tight logical and mathematical organization *(that makes one think of mathematics and Euclid's*[102] *elements)*. Through these books Miro learned to appreciate some aspects of music as a craft (rather than art), expressing music as simple arithmetic. Miro never shared the program with his professor *(because I didn't want to make him think he could be replaced by a machine).*

Miro has also advised his friend mathematically on how to design programs that facilitate the practice of music. While practicing, for example, the program displays music notes popping up that indicate to "bring out the melody here," and can help accomplish correctly a ritardando (i.e., slowing down), especially when it occurs over several measures *(it's like a programmable metronome*. *Imagine if you have a metronome that you could program the piece, so that ok, the first ten measures are at 80, it gradually speeds up to 100*, *and then, and so on).*

Third, Miro experienced the synthesis of the two disciplines into the new field of computer-music. For his master's thesis at BU, Miro investigated the history of computer music. Later, in

[102] *Euclid's Elements* is a series of books that develop and present the science of geometry and other branches of mathematics using logical development.

1980s, he also served as president and treasurer of the New England Computer Music Association (NEWCOMP[103]), working with its founders to produce several concerts of computer music.

Finally, Miro thinks that some music skills transfer to computer-science skills. For Miro, arranging music for an orchestra is like programming. An orchestral piece includes a set of instructions for each musician and possibly for the conductor, eventually producing music. Similarly, when the computer follows the program's instructions, if they are written correctly, it produces results like a graphic drawing, computation, or some dialog with the user. Believing that commonalities between the two disciplines can also be revealed through thinking of their differences, Miro points out that while music performers bring along their interpretations, computers just follow instructions *(it's just the same idea… if you have this type of process oriented thinking, you think in terms of written notes that you read and interpret and produce this um, this work of art that unfolds over time, just like computer games or reading a novel or like listening to a symphony)*.

Although initially Miro suggests that the aesthetics dimension does not come up in programming *(making it sound good, that's not an issue in computers),* he takes it back, recalling his user interface work, ensuring the user interface is attractive and intuitive. He believes that both music and computer science share aspects of both art and craft, agreeing with known composer Walter Piston's notion that there is craft in music in addition to art *(it's kind of like the counterpoint I told you about, where ok, here's the tools you need, here's the craftsmanship you need before you can do the art),* and with Donald Knuth's suggestions

[103] Founded in 1981, NEWCOMP's mission was to promote computer music of all kinds: sound synthesis by computer, computer-aided composition and algorithmic composition, live performance with computers, etc. NEWCOMP brought computer-based arts to a wide audience through performances focusing on music but including also other arts, computer-music competitions, conferences, and courses.

in his book *The Art of Computer Programming* that computer science is also an art and not just craft.

Miro compares his feelings of having a computer available for him to program, to a pianist who can do anything with their Steinway Piano, or to a violinist who can do anything with their Stradivarius *(it's like, there's this tool, and "oh let's see what I can do with it!").*

Miro feels that the structure of musical compositions resembles computer programs *(very often in a computer program you'd have … an initialization phase, a startup phase, like am operating system for instance… and then you have the running of the program itself actually doing all of the work, and then you have a shutdown phase… a music piece has an introduction, and then you have the main body of the piece, and you have the coda).* In addition, a computer program shuts down gracefully, similar to a piece of music that comes to an end.

Starting music practice early instilled in Miro the tradition of working hard at a discipline and then enjoying the results, discouraging instant gratification *(the fact that something to start with is difficult and you work at it, and you spend a lot of time working at it, and you get good at it, and it's enjoyable, and people enjoy what you're doing, that's basically the skill of discipline... it's the opposite of instant gratification).* Miro believes that practice gets pianists into flow *(professional pianists practice about eight hours a day, and, they've got a certain ah, flow going there)*, similar to the way programmers maintain extended periods of concentration in software design and implementation tasks *(the concept of flow where you get to a certain level where you're just kind of cruising, you're productive happens a lot for programmers, writers and designers).* Writing a program involves mentally organizing things and just getting started can take a long time. In the past, while working, Miro used to practice the piano on and off, depending on his schedule *(I'd get busy on work and I wouldn't be practicing at all for a* *few months, and then I'd start practicing again).* Currently, Miro practices the piano for about an hour or two a day.

Miro believes one never loses the skill of piano playing when one gets older, especially if one had piano lessons *(it's something that does stick with you… if you're away from it for a long time you lose a lot, but you don't lose the whole thing).* Moreover, no matter what one studies, a person always brings along some skills *(whatever the major is, you have to have certain skills),* which in Miro's case are the music skills he can use as an amateur musician throughout his life *(just the experience of having four years concentrating on music–invaluable).*

Miro experienced some career choice conflicts throughout his life. Upon graduating in music from BU in 1973, he wanted to go into computers because he felt that a musician's life is not steady, is away from home *(they have a very precarious life… I like to be at home every night)*, and not financially rewarding *(I like to have a steady pay check).* Moreover, professional players need to market themselves and find sponsors. The alternative of becoming a music teacher was not attractive either *(I never felt I had much affinity for teaching… I didn't feel like I knew enough to be a teacher*), neither was the option of becoming a piano accompanist *(it wouldn't really be much fun).* With not many career options left in the music field with which Miro could make a reasonable living and enjoy music at the same time, he started pursuing a part-time programming job *(so I'd have more time to practice... I think actually common sense took over in that I really enjoyed the programming, and, and the computer business).* With time, Miro began perceiving music as a discipline one can get a lot out of as an amateur *(this is just fascinating to me… if you're a doctor, you can get your friends together and play music for fun. If you're a musician, you can't take out other's appendix for fun… you cannot be an amateur doctor, you cannot be an amateur lawyer*). Moreover, professional musicians, as other performing artists, are told what to do and cannot turn down work, while amateur musicians can choose what they want to play. It was surprising and counterintuitive for Miro to learn about the discontent of professional orchestra players *(of all the different professions, there's a very high degree of dissatisfaction among orchestra musicians… I always thought, you know, if I could just get good enough at the percussion or at the tuba, to be in the Boston Symphony).* Miro contemplates that the reason is partially due to their lack of control of their repertoire and schedule. Similarly, he feels vulnerable as a computer scientist about not being able to show off his contributions to the numerous computer-systems he developed, as he is under a non-disclosure agreement.

Without music in his life, Miro would be a different person. He is a person of multiple worlds *(a circle of friends here, a circle of friends there)* which sometimes overlap *(where there's enough programmers you can find another musician among them),* and sometimes do not, like in the ragtime festivals where Miro is the only programmer. Miro hypothesizes that had he not invested all his free time in music, he would have pursued his Ph.D. in computer science and become a professional in the academic world *(that would make it easier to get a job in research now).*

Miro needs to be involved in all three of his worlds–music, computers, and animals *(I kind of need to have music in my life. I need to have computers. I've got to have pets… I think I'm happier having all three).* He is fortunate to be able to perform *(it's just a wonderful thing to be able to play concerts… it's fun to get together for chamber music things).* He is also happy to work as a programmer as it is a mental exercise he needs to have.

In summary, the main ideas in Miro's story are:

- Reads scores;
- Inspired in youth partially by TV to play music;
- Inspired by neighbors in music and math in youth;
- Listened a lot to records in youth (father's record collection);

- Loved mechanics of record player;
- Got involved with both music and math at an early age;
- Career conflicts: contemplating becoming a musician;
- Music discourages instant gratification and encourages working in a difficult discipline, with finally enjoying the results;
- Analogizes between computer programming and conducting an orchestra to produce music;
- Combined music and programming in a software program that produces Baroque music based on counterpoint rules;
- Sees math in music (e.g., counterpoint rules);
- Believing he is not good enough of a pianist to apply to Julliard or a school of this caliber;
- Music skills help in programming (e.g., typing);
- Sees aesthetics in both music and in creating a computer program;
- Accomplishing a difficult music piece can encourage disciplined and challenging work in other disciplines;
- A man of details;
- Good sight-reader;
- Placed computer and piano in same room (occasionally would switch from one to the other to help solve a problem);
- Nervous during piano performance (because of bad memorization);
- Had a passing thought of becoming a pianist;
- Did not want to follow his father's job as a composer/performer (due to life style).

F. Meg

The oldest of three girls, Meg was always engaged in "boyish" activities *(I was supposed to be Bruce… I was obviously exposed to a lot of testosterone in the womb)*. She loved building car models with her engineer father, taking apart their VW buggy and Renault in their driveway in Chevy Chase, Maryland, with the neighborhood kids watching. She also built WWII model airplanes with him. Marveling at her father, Meg describes him as fascinating and very popular in their neighborhood. Meg remembers the day he bought her a crystal radio when she was six years old *(so we very carefully, you know, wrapped the wire and everything, and it was just magic).* She recalls memorizing her father's cryptology lectures from the book *War Secrets in the Ether* and George Gamow's science book *One Two*

Three he bought her. She idolizes her father, a survivor of a difficult childhood and a war *(he was a pilot in WWII in the Pacific, and you know, was shot down I think once and had a crash landing and survived).*

In her childhood, Meg discovered she had good spatial/visual skills when she was obsessively drawing maps and was the best student at solid geometry in her competitive junior high school. To date, when giving driving directions to women, she says "head north," which is typically how men absorb directions *(and that's how I express it. Women do things by landmarks, you know, so I have to always think, "ok this is a woman, 'turn right at the Dunkin Donuts.'").* She was also interested in astronomy, stargazing with her telescope, experimenting with chemistry sets, and obsessively reading dictionaries and encyclopedias. She loved to collect rocks and document her findings, and research Egyptian Gods, creating detailed miniatures of the pyramids at Giza. She loved building with Lincoln logs *(I was really ticked off that my parents wouldn't get me an Erecter set because I wasn't a boy)* and is still surprised she did not become a building architect.

Meg grew up in a musical house with her mother, a former CIA analyst and concert pianist, and her father, an amateur musician who sang and played stringed bass *(it was really wonderful so clearly we had an environment where I was encouraged, right).* Meg's sister, now a professor of Medicine, plays the violin at the McLean Symphony Orchestra and has a string quartet. Meg used to accompany her maternal grandmother, a church organist for 60 years, to church *(having to sit on the bench with her, and watching her do all the stops and the pedals and kind of stuff which was very exciting).* Meg also enjoyed listening to her mother playing the piano *(lying underneath the grand piano with my mother playing the Mephisto Waltz by Liszt. (laughs). Like really cool, like I loved it.).*

Meg started learning to play the piano at three *(I was able to read music before I was able to read written English)*. She was taught by her mother who was critical and a perfectionist *(that's probably one of the reasons I chose another instrument).* Her mom's criticism along with her frustrations of being denied a string instrument because it was not ladylike, and her voiced opinion of the piano being a non-orchestral instrument, made Meg quit the piano. Despite her mother's criticism, Meg never considered practicing a burden and was self-motivated to play. At an instruments' "petting zoo," Meg fell in love with the oboe but started with the flute, hoping to take on the oboe later at 13, but ultimately stuck to the flute (see Figure 9).

Figure 9: Meg performs with the flute (outside of Graves Hall music building, Phillips Academy, Andover, MA, 1980).

Meg's mom continued to be involved in Meg's musical life with the flute by accompanying her on the piano during Meg's practice. She drove Meg to lessons, waiting in the car *(extremely courteous about respecting sort of the teacher-student thing)*, and occasionally joining Meg once Meg's teacher got a harpsichord *(and that was really quite a big deal and he was very impressed she played so well and everything)*. Meg appreciated the opportunity she had playing with her mom, recalling their playing of the 'E' flat major Bach flute sonatas, where her mom had to work hard playing the harpsichord, so different from the piano. Meg's mom continued accompanying Meg throughout high school, until her eyesight began to deteriorate *(she was awfully dedicated in doing that, and I very much did appreciate that it was fun).*

Meg became successful at the flute, winning competitions and being encouraged by her grandmother, who played the organ in church, and by her personal band leader, a trumpet player from Julliard. At 16, she already performed with the Baltimore Symphony and received high praise. Her high school years (she was skipped ahead one grade) were her best musical period and are the reason she went into music. She loved to travel with the junior high and high school orchestras and experience new cultures *(and we just played, you know, a phenomenal repertoire, and you know I had wonderful summer experience).* On one of her summer tours to the University of the South in Tennessee, she met kids from Louisiana, Tennessee, Georgia, and Alabama, shared a room with a Japanese student, and befriended a phenomenal African-American violinist *(just an enormous, kind of cultural change, and ah, very much of a southern culture… I've got to say they were very open and advanced for that time)*. She had never before experienced that kind of diversity *(this was just really eye opening)*. This experience influenced Meg to send her son to boarding school, to have an eclectic experience rather than a homogeneous cultural experience. She also toured with her youth high school symphony orchestra in Europe for an International Youth Symphony Orchestra festival in Switzerland, Austria, and Italy. This tour enabled her to use her high school German and French, and befriend Czech students still living in the Iron Curtain days, with one becoming her pen-pal *(culturally it was really neat to kind of have that opportunity to, you know, meet people from what seemed like a really foreign culture and yet we found out, you know, it's like, oh music is a universal language. We had no problem getting together and concertizing).*

Music helped Meg cope with her possible Aspergers disorder as well *(it was really kind of my thing in junior high, because I was very shy, and I was socially awkward and I probably have Aspergers, my two younger children too… so I didn't feel that I fit in very well in junior high school).* As Meg became more confident with her flute playing, and with the added encouragement of her junior high school band director she started feeling better about herself *(and it just, it just was really like "wow I really fit in here.").* She suddenly felt a sense of belonging *(it was such a strong visceral sense of "oh I belong here" that I had not felt, you know very much of, you know, otherwise… and it was like the music could really sort of do my talking for me)*. For Meg, music meant to belong *(that could be my means to fit into, to participate, to be part of something. I mean it was important).* She loved performing and finds it interesting that shy kids, like her son, are good performers *(I mean it's very, it's very interesting to me that a lot of times really shy kids are great at drama)*. Later, when Meg went into computers, it was a long time until she felt comfortable socially again *(but it took me many, many years in business before I was comfortable going into a room of people where I knew no one and I just had to go around the room and introduce myself, just spectacularly hard).*

While Meg enjoyed her flute playing in her high school youth symphony, she had a difficult time during her undergraduate years at NEC, particularly with its president, Günter Schuller, who prevented her from graduating with honors *(although the faculty elected me to the Honorary Music Society).* She struggled socially at NEC *(I just found it's… exceedingly competitive… and there was just a great deal of politics involved in, you know, who got what parts and so forth, and it just turned me off*). However, music became important to Meg when she was asked last minute by the president of NEC to play the flute solos in *La Bohème* and *Il Trovatore* with the NEC orchestra on tour in New York City at the Alice Tulley Hall *(and I did a pretty good job).*

Meg went to NEC specifically to study with James Papadakis, a Boston Symphony flutist, a wonderful, patient person and a real gentleman. At NEC she also studied with Paula Robison, a well known flutist. Thinking back at what she learned she was disappointed *(there's nothing that really stuck with me… I never really felt that there was, you know more than–I don't know, kind of a couple things where, you know, maybe they gave me some real insight).*

Meg also remembers her three flute teachers during high school. Her first teacher, considered by Meg an amateur, was a neighbor, and wife of a politician *(I remember her having to wipe lipstick off of the flute).* As Meg progressed she moved on to a professional flutist, Mark Thomas, whom she liked *(he was kind of relatively conventional, sort of pedestrian kind of person, you know and player. Um, you know not hugely inspirational).* Her third teacher, Britton Johnson, a principle flutist with the Baltimore Symphony and protégé of flutist William Kincaid,[104] was a great musician, though somewhat odd *(he inspired me to think about music in a completely different way).* Once when she had to produce a soft and sudden sound on an extremely difficult note, he asked her to think about the note as if it were a Chinese child where Chinese culture takes the gestational time into account *(when a child is born in China, the child is already one year old),* implying she should be mentally focused on preparing the note, so that it takes no additional thought or preparation when she plays it, accept for just releasing the key. His vivid analogies were inspiring for Meg as she was a concept-oriented kind of person *(I'd really see this not being the teacher for a lot of very,*

[104] William Kincaid, (1921-1960), is one of the most influential flutists for American flute players. He was the principle flutist in the Philadelphia Orchestra.

super-duper concrete detailed people, they would not get it… But it really works for me). For Meg, Britton Johnson is the real standout talent, truly unique both as performer and as a teacher.

Meg also met her bassoon-player husband, 16 years her senior, when they were both playing for Chorus Line in Boston in 1977 *(and he was quite well known, better known than I…* so *in this one show we kind of landed together and that's, that's where we met, and kind of immediately, it was kind of like my fate).*

Music became particularly satisfying for Meg when she met Robert Koff,[105] a violinist and founding member of the Julliard String Quartet *(he's like one of the most interesting people*). Meg, five months pregnant with her oldest child, was courageous enough to ask to audition for him *(which was a huge, you know, aggressive feat for me)*, and remembers to date what she wore and that her husband came along. For the next 20 years they played chamber music concerts, with Meg playing mostly the baroque flute *(he was the person I wanted to play with, you know the most).* They recorded a lot and travelled to New York City to perform *(the Robert Koff connection was really kind of nutritional for me in terms of music, because I just enjoyed so much playing with him. He was just so fantastic).*

Her first encounter with computers was during a visit to her parents' home in Virginia, in 1978, when they were playing with the little Timex Sinclair computer her father bought *(we could program it to do things like, draw in lips, and it would go like, these boxes like "boop" (laughs), It was hysterical. But I remember that really well, I felt like "oh this is so interesting.").* When a piano teacher who taught with Meg at the Philips Academy decided to retrain in computer programming, Meg decided to follow suit *(so I was like, kind of*

[105] Robert Koff pioneered early music in Boston, and in the early '60s retired from the Julliard String Quartet to head the music department at Brandeis University

impressed by that. I felt like, "hey if Barb can do it, you know, I can too."). While going through this retraining program in 1982, Meg met and bonded with former musician acquaintances. This six month program was exhausting as she had one child, had to do projects after a day of classes, and then teach her flute students at night to make money. But it was worthwhile *(It was great training for startup companies which I've done four of (laughs))*. There she studied programming languages like Fortran, Cobol, and Assembly language for the IBM 360, in addition to taking a database course. Despite the recession in 1982, the year she finished her courses, she managed with the help of the father of a student, who happened to be a Vice President at Draper Labs, to get a job at Draper Labs *(what was really amazing, this was another total accident of fate, this is how things work in life)*. She started with mounting and dismounting tapes on the DEC PDP 11/40 computer *(the most lowly of the low jobs).* Gradually, Meg progressed to debug other people's codes and program a little. In 1982, after her mentor, a fellow from MIT, taught her the programming language, Pascal, and object-oriented design, she became part of the programming team. At first, Meg was not bothered by her low salary as all she desired was to work at that research environment *(so ah, money is not usually what has motivated me, you know, in my career… I was barely making more than I was making as a musician).* However, after a year or so, she moved on to consult for Higher Order Software, a startup company, developing an emergency transportation program *(and it was all mine!)* and an FAA[106] flight corridor[107] system for the Department of Transportation, until the whole team was laid off.

While at Draper, her favorite mentor, Mike Ash, who also taught at BU's computer science department, pushed her to study *(so one of the other really wonderful gifts that I got*

[106] Federal Aviation Administration.
[107] A flight corridor is an area in controlled airspace that allows aircraft that are not flying under radar control from the tower to fly over a certain area.

from working at Draper… they said, "you've got to get credentials, you won't get anywhere here or frankly anywhere else."). In 1983, Meg enrolled at BU's MET for a graduate degree in computer science *(I had three different pregnancies during the time I did that degree. I had to withdraw from several classes because I was in a start up, and it was just like 100 hours a week and I couldn't possibly do a class)* and graduated in 1990. This degree was instrumental in making Meg become a chief architect, designing large systems and managing large teams *(that's kind of the great thing about doing the degree in tandem with working and developing work experience)*.

While working on her degree in 1984, Meg joined a startup company, DAS (Data Acquisition Systems), that developed real-time graphical process control systems, working as their chief architect. She was then recruited by a database guru to work at Fidelity Investments where she invented a patent and got involved in telephone systems and customer relationship management. From Fidelity she moved on to become the chief technology officer, and then the VP, of the portfolio management software division at Thompson Financial Management. She then decided on a career change, taking a huge pay cut, and went to the Whitehead Institute that subsequently became the Broad Institute at MIT and Harvard, working for over six years in the informatics division of the genomics project. In 2008, immediately after Broad, Meg joined the Cambridge Research Institute (CRI), a genomics startup company as their director of software development, using AI and computer vision techniques to quickly distinguish cancer cells from non-cancer cells when looking at thousands of slides. After 18 months there she was recruited to work at Good Start Genetics, her most recent startup company where she is now the third employee, doing pre-pregnancy genetic screening tests for disease carriers.

When working on her computer projects, Meg cannot think about music *(I'll tell you in all honesty I cannot listen to music when I'm working… Oh well I don't think of work at all when I'm playing. (laughs) I'm like in the zone …)* Similarly, Meg wouldn't be able to drive with music on, because she would drive to the music *(if it's a really fast movement I'm starting to speed, if it's really slow I'm going too slow, people are honking).* She is unlike some other musicians like her former colleague from Philips Academy, a cellist, who absolutely has to listen to music while working *(he was absolutely addicted to music If he was not, you know, working, you know at the music department and everything, he had to be at home with music on, I mean he had to have music every single minute, you know. And I'm not like that)*.

Performing while working was difficult depending on how in-shape Meg was with the flute *(so if I'm out of shape like I am now, and I'm having to work pretty hard, you know to get back into shape and everything, It feels much more like a chore, you know to have to do it. When I was, you know, in shape, it was completely relaxing).* Meg would like to get back to the times when performing was more like a relaxing event *(I just really enjoyed it and it sort of took me away, you know, from, you know the stress or work).*

Meg observes that it is hard for her to switch between playing music and speaking about music *(you use different sides of the brain when you are speaking versus playing, and I found that I had real problems switching over)*. In 1985, while she was working for the process control startup company, she gave a lecture/demonstration series with Robert Koff, featuring the J.S. Bach Musical Offering, celebrating Bach's birthday. Meg found it hard to switch between playing and talking about the music *(I had to be awfully careful to just, even if I thought my instrument was in tune, I spent a couple of seconds tuning on everything, and* *then play the piece, if I rushed into it too fast I was kind of off kilter and somehow unbalanced, 'cause it's just like takes me sort of switching effort to get).* Meg hypothesizes that the audience, too, may have needed time to switch over from the words they heard to getting prepared to listen to the music.

Being physically away from work for that lecture/demonstration event, Meg felt completely transported from work and felt more rested *(it was as if I'd had a three week vacation at the beach where I could just sit there and read. It was amazing. And I don't know that it lasted necessarily long but I remember feeling like I was so absorbed, you know in doing that).* While for many people music activity in parallel to their intense computer-science job could be hard, this experience was energizing and refreshing for Meg.

At times music performances in addition to her work made it hard on Meg. She recalls finally getting to audition at the opera company in Boston (where her husband played), at exactly the end of her computer retraining program, and while still contemplating between music and computer science. That stress combined with her flu caused her to fail.

Lately it has been hard for Meg to combine her work with music practice and performance, except for some weekends or evenings, but she wishes she could *(I think I'd be more mentally healthy if I had been able to do that).* She manages to maintain mental continuity with music through her trustee appointment at the All Newton Music School, where her children took lessons and she taught, also attending their wonderful concert series *(and I've really enjoyed being a concert goer again)*. Recently, Meg combined her music and computer-science worlds through co-designing a music-technology curriculum for music teachers, delivering its first workshop through the Boston Symphony Professional Development Program (see Figure 10). The curriculum included the use of Sibelius software for writing music arrangements and musical notation; the use of media software suite like iTunes, iPhoto, and GarageBand, behavior management techniques for music teachers, African-drumming rhythm,[108] and Meg's class on M-STEM (Music relation to Science, Technology, Engineering, and Math), which addresses similarities between writing a software program and a piece of music, sounds variability, brain activity while improvising, pattern recognition connection to estimation and prediction, and the use of technology in music and the arts.

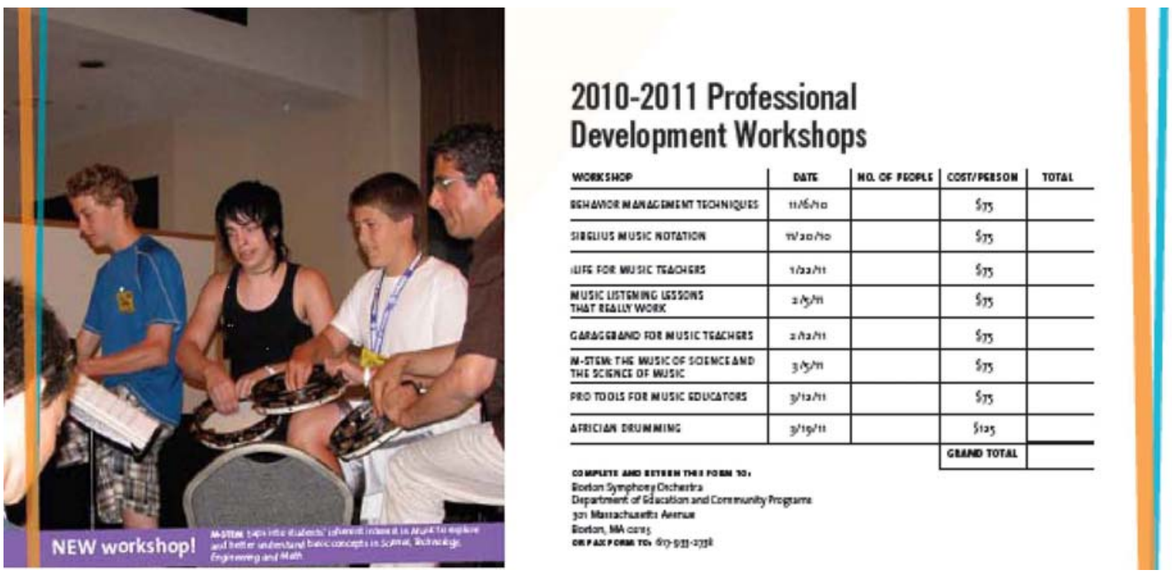

Figure 10: Meg presents M-STEM: Music of Science and the Science of Music, Interdisciplinary Curriculum, 2010-2011 Professional Development Workshop (Boston Symphony Orchestra, Boston, MA).

Meg thinks that the connections between music and computer science are powerful *(but subtle and ah under the surface)*. If and when we will explicitly experience and articulate these connections, it would mean they are not valid *(the fact that it is sort of buried and natural and so forth that makes it um, so powerful)*. Still, Meg was able to describe some high level connections.

[108] A rhythm in which temporal units are constructed by concatenating (joining end to end) a series of smaller units into larger units of unequal length, such as a 5/8 meter produced by the regular alternation of 2/8 and 3/8. This is contrasted with the divisive rhythm in which an integer unit is regularly multiplied into larger, equal units.

Teaching flute, which Meg did at the Philips Academy and at the All Newton Music School, helped her in managing software projects as she brought her experience in building one-on-one relationships when she taught private flute lessons to her students *(I was able to form so many one-on-one relationships through teaching for so many years, 'cause see I started giving flute lessons back when I was about 14 years old. You know so I taught from the age of 14 to about 28… but I think that gives you a lot of insight into, you know, into people, and bonding around music, I mean it's sort of hard to hide. You can't really disguise who you are, when you're expressing yourself through music).* Although Meg was socially shy in her childhood, she succeeded in managing teams of people in her projects because of that ability to create one-on-one relationships. Performing, in addition to teaching, improved her ability to connect with people at work *(the performance and the music making it possible for me to understand what it meant to connect with other people, connect with an audience had been really important… I use that every single day).*

At her work, she enjoys working in teams as well as alone. Sometimes working in teams is productive for Meg, and other times she needs to think through the problem by herself and only then provide a recommendation to the team. Similarly, in her flute playing, Meg enjoys practicing on her own as well as with a group.

At the Broad institute, Meg experienced one of the most interesting types of music parallels when she co-presented to an audience of several hundred scientists, the design of her system that identifies genes-disease causal relations. While her colleague presenter would get nervous and would bore the audience *(give this boring laundry list recitation of the technologies),* Meg was equipped with the confidence she acquired through her extensive music performances and with the sensitivity to her audience *(they're bottom up kind of thinkers... very inductive and would not* *be interested in hearing grand plans for software and software architecture).* Using these two qualities she explained to her audience in a way they would understand the issues involved when they specify the input data to her system. The most exciting aspect of this presentation for Meg surfaced when her audience commented on her effortless but effective presentation *(it's easy for me because I've given thousands of public performances, because I've had a lot of road time doing this stuff… there's no question that the, you know, the ability to have done many public performances has a tremendous affect on being able to communicate effectively)*. She dismisses her parents' complaints about her music degree not being used, as she recognizes its contribution to her ability to communicate effectively. This ability is useful especially in large software projects like her genomics project *(you have to have a lot of resources and a lot of people).*

Meg's sometimes innovative practice means for overcoming a difficult flute passage have informed her problem-solving skills to use creative thinking when she attempts to fix a bug in her computer programs *(you've got a bug or something, until you can solve it and try to create different ways to handle it and so forth. Kind of parallels creative different ways to practice something that's a difficult passage that you've psyched yourself up about, and you can't play anymore and you have to try different ways)*.

Meg's ability to focus, which occurs during her music performance, persists also during her computer work *(I sort of see the parallels with those kinds of things for sure… the whole discipline of, you know, just being able to concentrate and stick to something like that… it feels to me like when I'm, when I'm really engrossed when I'm really engrossed in thinking about, you know, solving a computer-science problem, it's just the same when I was engrossed in a performance, and you kind of get in the zone).*

At the same time Meg feels that playing music allows her mind to wander *(I've come up with some of my best ideas, best you know problem solving when I'm not thinking about it).* When she practices a difficult flute passage very slowly, Meg needs a distraction like watching a Celtics game *(this distraction puts my brain in kind of an altered state*, *where the information would sink in really, really well, and then inevitably when I'd wake up the next day, I'd either be able to play the thing, or I'd be able to play it much better).* When Meg plays the whole piece completely, she cannot have any distractions *(I'd do the run through of the piece, you know completely concentrating on it).* It is hard for Meg to practice without a goal of public performance *(just sort of practice for its own sake is a little tough for me, so it's taking me some effort)*.

Another factor in her music that affected Meg's computer-science work is perfection, which is required in both music and computer programs because neither can be successful with only 90% accuracy *(because if there is a bug in your computer program, it's good chance it might not run, or it's going to produce possibly a really bad effect. If um you, you know, play 90% of the notes right in the piece, you stink. If you get a 90 on a really tough chemistry exam, you think you did really well!).*

Meg thinks that her spatial/visual ability contributes to both her musical and mathematical skills *(there's no question that there's a lot of relevance between spatial ability, mathematics, and music. And um absolutely they go together).*

Mathematics helped Meg with her rhythm problems *(break down very complex rhythmic patterns into essential twos and threes and put them back together).* She borrowed the breaking-down idea from her computer-science experience *(that's kind of what you do with computer* *science or when you're doing engineering right)* and from one of her friend's sayings *("we have to take this huge big elephant problem and turn it into elephant burgers.").*

Meg's exposure to the flexible, additive African-drumming rhythmic system *(it's not confined within those you know clearly delineated measures, division based)* through an orchestral piece conducted by Gunther Schuller at NEC, informed Meg's design of software systems. The incremental build, which is characteristic of African drumming, helped Meg in designing adaptive and flexible software systems in genomics and genetics, accommodating scientists who are not able to describe what they wanted from these systems upfront.

When Meg recalls her math and science teachers, she favorably remembers her eleventh-grade chemistry teacher who encouraged her to go into sciences in college *(but for whatever reason I think I felt more comfortable in the milieu of music).* His class was difficult, involving complex mathematics, but was wonderful *(he was a character, and had some big job at what is now called 'NIST,' what used to be the National Bureau of Standards. Oh he was hilarious).*

Although Meg was good at math, she was not encouraged to flourish in that field as she grew up mostly in a southern culture *(girls really were not supposed to be good at math… it was very difficult, you know for me. Junior high, in particular).* Her tenth-grade math teacher, retired Admiral Brody *(firmly believed girls cannot possibly do math),* never called on Meg or the only other girl in class *(for the first time in my entire life I got a 'C' in this class. So it just finished me off in math).* She believes that had her parents been Jews rather than WASPs, they would have contested the teacher's attitude *(my parents were very WASP parents, did not fight about this really… I sort of wish at that point I had Jewish parents* (*laughs*)*, because they would have marched up to the school and slapped this guy around! I* *know they would've).* Meg did not take a math class past tenth grade. At the same time Meg had a wonderful Biology teacher, Mr. Shank, who helped offset her bad math experience, running interesting chick experiments with his students *(and it really goes to kinda show how many positive experiences are needed to really offset a negative one for a kid).*

Meg has been supported by good mentors at work *(I've got to tell you that kept me going, through thick and thin… so I have a lot of gratitude to those people)* and feels every engineer needs a mentor. She is grateful to her mathematician colleague, Mike Ash, who hired her at Draper Labs and encouraged her to continue for a graduate degree in computer science *(he was a lovely man… so he really encouraged me, he said "look you've got to take some classes*.")*.* Meg is also grateful to Ernest Sabin who mentored her in Operating Systems at Draper Labs *(he is the greatest guy, he's just, he was like this guru, he was god at Draper. They just loved him, worshipped the ground he walked on).*

Throughout her life Meg experienced career changes*,* starting as a professional flutist *(I actually never did anything but music from the age of fourteen until I changed careers… I was a kid professional musician).* Her unpleasant experience at NEC stayed with her, ending her desire to become an orchestral musician *(I saw myself as somebody who's going to become an orchestral musician. Leaving NEC I saw myself as somebody who would never do that).* After a busy period of chamber music performances*,* when Meg turned 27 and had her first child, she stopped doing music full-time and kept teaching music for a while but was seriously thinking of a career change. Knowing she was the main breadwinner and that her husband would not move to New York, even though they both could have had a richer musical future, reinforced this career change. At first, Meg planned to integrate her music playing with work on a daily basis *(I'll just do this boring day job in computing and I'll be doing my music at night).* However, due to the demanding nature of her work, her plan did not materialize and she became a full-time computer scientist.

It was a difficult transition for Meg *(it's like a mourning process. It was as if somebody had died... It took me a long time to sort of feel, you know ok about the fact that I was no longer, my identity was no longer, you know as a professional musician… because of the fact that when you're an artist and I've been a musician from a very young age, and a professional musician from a very young age, it's you know, it's impossible to separate out who you are in the music. It's like the artist and your personality are one. And this was a very scary thing, It was sort of like severing myself, in half, you know by changing careers, and um, I think particularly because of the fact that, you know I didn't stop doing music because I was terrible at music, I stopped doing music, you know because I had a lot of other obligations and I think I just didn't feel like a, a selfish enough person to make my children suffer, You know, had I been poor).*

It has been a long painful process for Meg to enjoy music after transitioning from a professional to amateur musician, feeling that she is out of shape with the flute. But now Meg finally enjoys music again *(without feeling like it's work, and actually going to concerts and enjoying somebody else sweat).*

With her husband's death in 2005, it became hard for Meg to go to concerts in Boston, especially the ones where she would see all the musicians he played with in the pit or on stage. Her husband used to get tickets for their friends and for their daughter and her schoolmates to his shows and rehearsals *(so she had this really amazing relationship with him)*. Recently, Meg has been taking her younger kids, who are interested in the theatre, to a show at least once a year, giving them some exposure to the life she had with their father. Although at the beginning it was hard for Meg, it has changed now and she finds it liberating. She now enjoys playing opera arias (her husband loved opera), Romantic music, and Mozart, but loves J.S. Bach the most. Occasionally she would perform colonial music and fiddle tunes in lecture/demonstrations for historical societies. Her last challenging concert in public was in 2001, something she would have loved to get back to. She wants to get back in shape to play chamber music again and feels sad she did not keep up with it at the same level she played before changing careers. When she retires from her current startup, she plans to either teach computer science in a small college, finish her Ph.D. in computer science, or mentor young individuals who aspire to be information and technology executives *(because it's a lot like music …)*.

Life without playing her flute wouldn't be that great but she is not a music addict. Her computer-science world, although initially more about solving problems, is now a social thing for her as she progressed in her career and developed large systems as well as evolved in management and getting people to cooperate.

Meg has always felt she is a person of multiple worlds *(I've had so many interests throughout my entire life, and everything is interesting to me… I've been a relatively serious artist, you know I've done all this stuff in music, um tremendously interested in science and math, um you know I've done a great deal of writing…)*. The many computer applications she developed exposed her to multiple fields of study like pharmaceutical, transportation, manufacturing, genomics, etc. It is not surprising that with her multiple interests in the sciences and the arts, Meg plans to write a historical novel about poet and physician Oliver Wendell Holmes,[109] with whom she became familiar through the library she inherited from her great-grandfather.

[109] Oliver Wendell Holmes, 1809-1894, was a Boston poet who coined the term "Boston Brahmin," and became a famous author in 1840 through the Civil War. He became known for his "Breakfast Table" book series about

In summary, the main ideas in Meg's story are:

- Participated in orchestras in youth; and in chamber music groups through adulthood;
- Inspired by role model in music;
- Good at languages;
- Music group provides her with strong sense of belonging;
- Bonded with family members (e.g., her husband, her mother, her children) through music;
- Preserved the link to her mother through music, as her mother was a musician as well and taught her the piano;
- Mother taught her piano and pushed her to play;
- Was self motivated to play despite her mother involvement;
- Daily communication with people at work is attributed partly to connecting with audience and ensemble members;
- Effective presentation skills at work are attributed to music performances;
- Sensitivity to aesthetics in work presentation and in her systems development is attributed to her tailoring of her music performance to the audience;
- Feels *in the zone* while performing and at work;
- Playing in musical groups makes Meg happy;
- Enjoyed building with construction sets in her childhood;
- Had good mathematical skills;
- Was talented in music;
- Inspired by her father with whom she built car models;
- Perceives the big picture;
- Applies divide-and-conquer methods when practicing musical pieces and at work;
- Is aware of her good spatial/visual skills, which she uses in both music and work;
- Has architectural tendencies;
- Grew up in a musical house;
- Hard to juggle between work and music performances;
- Acquired an academic degree in music and later on as an adult acquired an academic degree in computer science;
- Music energizes her and makes her more refreshed and charged for work;
- Combined music with computer-science;
- Thinks connections between music and her work are powerful but are often hard to articulate;
- Teaching music informed her work, in forming relationships;
- Performing in music groups informed her collaboration at work;
- Her math skills informed her study of rhythm in music;
- Innovative music practice techniques informed her out-of-the box thinking at work;
- Rhythmic aspects of music informed her flexibility in the design of general-purpose software systems;

America finding itself through discussions, and his essay doctors carrying infections from patient to patient, starting the practice of doctors washing hands prior to examining patients.

- Experienced career changes between music and computers;
- Recalls some favorable music teachers and work mentors, but also some unpleasant ones.

G. Ethan

It was not out of the ordinary for Ethan, a New England kid, to attend Hebrew school. Being different and diverse was a salient part of Ethan's identity. He grew up with older, widowed parents and relatives from Holland, Korea, and Germany in the culturally mixed town of Brockton, Massachusetts *(I can say my background is that, it's a little bit different…).*

Ethan details the diverse origins of his family members: His father, who fought in WWI, designed and built houses but lost his fortune instantly during the Depression, and then during WWII he built ships in Massachusetts. Ethan's mother married, at age 33, a Dutch engineer who was later killed with their baby by the Nazis in Holland. She was an independent woman and worked as a telephone operator right out of high school at times when only men were employed as telephone operators. After getting remarried to Ethan's father she stayed at home but became socially active with immigrants. Ethan's wife is Latvian and their children have been educated in both Latvian and English. Ethan's twin sister was involved with the arts and playing the piano in her youth, and later became a commercial pilot, flying twin jets for a California based company. Ethan's late half-brother on his father's side, and who was twenty-four years his senior, was a B-29 bomber pilot dropping bombs on the Japanese during WWII. Ethan's Dutch half-brother on his mother's side was a trumpet player who also played the piano and then became a sales executive.

The town of Brockton used to be culturally mixed, especially at the beginning of the 20th century, with lots of immigrants working in its factories *(so I grew up with everybody).* With the new highway to Boston and rapid urbanization, the commerce was pulled outside of Brockton, and suddenly the place became a depressed area, especially when the Depression hit, but then resurged again after WWII. Ethan was influenced by the Jewish population in Brockton at that time, and for a few years even attended a Jewish Sunday school at the local synagogue, although his family was not Jewish. He was fascinated by ethics and Jewish values *(I had an uncle that was doctor… and he had one book called, it was a book on ethics, I was probably nine years old or something but I got into this, this discussion of what is ethics and what is all these questions, When I got to schull, there was a lot of that there, I wouldn't get it anywhere else, a lot of deep thinking, and I carry a lot of that myself, a lot of my ethics and the way I look at things)*. His family had strong ties with the Rabbi whom Ethan adored. Even some of the rehearsals in the Brockton symphony orchestra were in Yiddish, which Ethan understood because he spoke enough German.

In this culturally heterogeneous environment, the town of Brockton encouraged music education and flourished with musical activities *(everyone played an instrument. It was expected. I think the era, the parents ah, our parents grew up in the '20s and '30s, and they played an instrument, everyone played an instrument, and your children needed to know as well. I just grew up doing that… By the time I got to junior highs school… I had my own woodwind quintet…).* In this musical atmosphere, Ethan took up the drums, oboe, piano, and the bassoon in his youth (see left image in Figure 11). He was self-motivated *(when I studied oboe, I was practicing four to five hours a day. I was really into it… I was self-motivated for the drums)*, except for when it came to the piano. His mother, who played the piano a lot and well, made her children take piano lessons for at least two years, which Ethan detested because of his strict piano teacher *(she would rap on my hands until they bled, while I was playing to get the rhythm and so forth).* Although turned off, Ethan learned a lot and enjoyed piano playing later in his life, especially playing Haydn sonatas. After six years of oboe (and occasionally *cor anglais*–French horn) in the local Brockton conservatory and private lessons, he then continued at NEC preparatory school with Louis Speyer, an oboe player from France. In addition to practicing the oboe, Ethan's time was consumed by carving his own reeds *(a very time consuming operation, and you have to make reeds. They, they last anywhere from two to six weeks and then they're gone, so you're always making reeds).* At 18, while playing oboe with two different Rhode Island orchestras featuring a famous soloist cello player, Leonard Rose, playing Dvorak Cello Concerto with one and the Variations on Rococo Theme by Tchaikovsky with the other, Ethan vowed to take up the cello in the future *(this is a really beautiful instrument and someday I'm going to take it up)*, which he did first for three months while working in Dayton for the Air force and then recently, six years after he sold his last startup (see right image in Figure 11).

Figure 11: (left) Ethan performing with the oboe (2010); (right) performing the cello with his string quartet (2009).

With the exception of his mother's insisting on him playing the piano, Ethan never felt pushed by his parents to do things *(I never felt like my parents, for example, were saying "you should keep doing this," I know they were proud of me when they came to concerts and things like that, but, I think I had the motivation).* He was also supported by his older brother, a trumpet player, on how not to get in trouble, getting by with playing the piano for a period of time just because it was his mother's wish, and then proceeding with his desired instrument. Although not musical, his father gave Ethan emotional support *(he was um, the hidden hand in many ways, I didn't know this until after he died–he died when I was 16, I just turned 16, but um, as it turned out when I went to sign up for oboe, the head of the music department in Brockton called my father and said, "that's a very difficult instrument for someone that's 10 years old and we really don't, we don't encourage it." And my, apparently my father said, "well if he wants to try it, let him try it.")*

Orchestras were a major catalyst in Ethan's early musical life. It was his mother who introduced him already at age three or four to band concerts in the summer time, where he admired the drummers *(and I thought that was just, the greatest thing, and I really wanted to play the drums)*. He was inspired and played the snare drums and timpani in grade school orchestras and marching bands performing on Memorial Day, Armistice Day, and other holidays, but quit when he realized the mundane task of drummers in classical music *(in classical music, drummers don't play very much, a drummer's life is counting)*.

At the early age of 10, Ethan could sense the gratification and empowerment throughout his stage performances, experiencing the creation of sound and its perception simultaneously *(this instant gratification, you're playing and ah, you're experiencing at the moment, like a lot of art, it's one of those things where the, the application of producing sound, or whatever you're producing as an artist comes back to you instantly, and if you're doing it right, and so forth, it's gratifying… in a certain kind of way, you are producing something that for me was very empowering in a certain kind of way).* His empowerment is also sensed through his body *(these vibrations are just moving through you… and you're moving and the other people are moving, you're moving together sometimes, sometimes you're responding, but it's a very, it's a very* *powerful experience)*. This bodily experience is so powerful that it feels like out of one's body *(you're not doing yourself, you're looking down on yourself and this stuff is just coming out and it's perfect, it's just being created, it's just coming out of somewhere and happening).*

A slide ruler that belonged to Ethan's father triggered Ethan's curiosity in mathematics when he was eight years old. With the slide ruler he learned to perform simple operations such as tables, square roots, cube roots, trigonometric functions, etc. *(I found it very empowering that you could actually do the calculations very quickly… so I think to me, looking back at it, it was very empowering; mathematics).* He had a particularly strong appreciation for trigonometry, using it during Boy Scouts activities and when playing alone, figuring out the length of bridges and calculating distances for dropping bombs from a balloon when the wind is blowing.

A similar slide ruler turned up at the home of his neighbor, Mr. Kellaher, with whom Ethan used to discuss challenging math problems *(I walked into this kitchen, and there was this young man with a slide rule doing some kind of calculations, and I said, "oh it's a slide rule" and he looked at me like I didn't know what it was and all that, and I started explaining and he said, "well show me how to do this" and I picked it up and started doing calculations with it)*.

With his mathematical and trigonometry enthusiasm and knowledge, Ethan enjoyed building huge radio-controlled airplanes from parts and plans with his bomber-pilot brother, who sometimes took him along on flights. They also restored an old, broken pump organ, which Ethan then played, and an old television, which they watched in their shared room.

Ethan's relationship with music-making changed numerous times throughout his life, alternating between means for making money and a serious avocation. The passing of Ethan's father caused music-making to become Ethan's source of income at the young age of 16 and encouraged his tentative idea to apply to Oberlin College to become a professional musician. At

16, Ethan was no longer leisurely practicing his oboe and carving reeds. Instead, he was hired for money as a ringer[110] oboe player in orchestras on the South Shore, New Bedford, and Plymouth, as well as a singer in church and a member of the Rhode Island Philharmonic *(it was one of those situations where your back is to the wall, what do you do? You go out and you, you work*) (see Figure 12). For additional money he drove a 42-foot truck at night, purchasing vegetables and beef at Quincy Market in Boston and distributing it to the supermarkets in Brockton. This lifestyle of playing music solely for the sake of making money continued also while enrolled at MIT as Ethan needed to support his mother *(in college I was strictly working for money, I just had to make money, so I worked… I had a job in the Rhode Island Philharmonic, I did, as a ringer I would play in the Cambridge Civic Orchestra, wherever there was a need for an oboe, sometimes it would be like a concert, like Newton Symphony was putting on and they needed another oboe player or English horn player, or something, and they would call me, I was in the union. When I was in college, I sang in Kings Chapel down in Boston, I was a paid tenor)*. He continued as a paid singer right after graduating from MIT, performing tenor parts in a choir and in shows in the east coast and in Los Gatos on the west coast, until he began working at Lincoln Labs.

[110] An occasional professional musician hired to strengthen an orchestra.

Figure 12: Ethan's first paid gig, Handel Oratorio (playing the oboe, directly below standing soloist, 1959).

Ethan's tentative idea of becoming a professional musician faded away during his senior year of high school. First, the Sputnik launch in 1957 inspired Ethan to study the sciences *(I remember going out there at night with a friend and watching the, this satellite saying, "we are really in a lot of trouble, we are really in a lot of trouble" and that motivated me more, even more in the sciences).* Second, he felt that a musician's life is pretty awful *(if you're a performing musician, typically you're either making an awful lot of money or you're making no money at all. And if you're making no money at all, what you do is you go into teaching. And at that time in my life, I really didn't want to teach music, I just, I wanted to be a performer).* Finally, wanting to support his mother, he felt that pursuing the sciences will be a better financial decision *(going into the sciences and engineering would be a better thing).* Indeed, as soon as Ethan started to work at Lincoln Labs, he no longer needed to play music for money, so he started playing in orchestras as a volunteer oboe player.

In fact, from early on in junior high, Ethan was interested in both the sciences and the arts, and in high school followed a dual-track path–sciences and liberal arts populated with science courses as well as history and languages like Latin, Greek, and German. His knowledge of languages enabled him to enroll in two years of humanities in German at MIT, where the lectures, books, papers, and exams were all in German.

Ethan was first introduced to computers when he enrolled at MIT in 1962. At that time, colleges did not have an official computer-science discipline and computer programming was taught by outlets like IBM schools. Quitting his truck driving and ringer job so he could study at night *(it is a lot to be studying and working as a musician)*, he got a semi-programming job at MIT working with tabulation machines.[111] Following this job, he became employed by the MIT administrative department that handled alumni relations as a student programmer for 18 months, writing mostly in assembly language and getting paid quite well. Working with the big computers (e.g., IBM 1401, DEC PDP-1, IBM 7090) available at MIT, Ethan was exposed to issues in system design and entertained writing large programs.

Running out of money at the same time as receiving a sudden offer from a friend to join him at the Defense Intelligence Agency (DIA), made Ethan temporarily leave MIT after his sophomore year and start a job in Dayton, Ohio, identifying radar installations in the Soviet Union. Within six weeks of working offsite, as he did not have security clearance, Ethan developed initial software to solve the problem. After a successful demonstration of the software by his friend to a branch of the Air Force Department, Ethan was issued an immediate security clearance and he was promoted as the project technician, with six adults working under him. Desiring to return to MIT, the DIA provided for his remaining undergraduate degree and enabled him to continue working on his project at the Hanscom Airfield Base in Bedford, Massachusetts. During his senior undergraduate year at MIT, Ethan had serious thoughts about music as a professional career again, but decided to continue working with computers, thinking that music would be too risky for him.

[111] Electrical boards that process data stored in punched cards.

Ethan continued working for the DIA for 20 years, 10 years with the Air Force, and 10 years with the Navy, all at Lincoln Labs, an affiliate of MIT. During these 20 years Ethan worked on the design of various missile guidance systems such as the Apollo guidance system, GPS satellites to covertly locate submarines, the Air Force's Minute Man Missile, and the AMX missile. During that time he obtained two graduate degrees from BU *(I was always interested in operating systems, because I was working with them, I was writing systems for a variety of computers and I was always interested in, in performance, how do I say this, building models, performance models)* and taught graduate courses including mathematical analytical models of operating systems at BU's MET's engineering department for 12 years (1974-1986).

When peace began to break out around 1985, with the Soviet Union collapse and Reagan's Star Wars initiative dwindling, Ethan left Lincoln Labs and began volunteer work helping minority companies, writing grant proposals for loans to help install computer systems, and employing graduate students from BU who worked pro bono. Soon after, he also started a small software company with six people working for him, developing software for industrial automation robotics for large companies such as banks to optimize their systems. That was sold after five years.

Ethan found his work on simulations for the missile guiding systems empowering *(We did a lot of simulation of ah, things like Apollo missions, Um, we would simulate the environment, we would simulate the vehicle, we would do things like accelerations and so forth and we found some very interesting things in the simulations… empowerment, its empowerment, that you can build a model, a predictive model… and you can then, ask all these 'what if' questions, what if we pushed it, way beyond this thing, what breaks or what's the limiting factor on this? So we* *could ask all of these questions and have a pretty good idea of what's going on. Very empowering).*

Ethan's life is a chain of unexpected turns *(to a great extent, my life has not been planned, Ah, I didn't plan to become a programmer, I didn't plan to be on oboe player, Um, I didn't plan to work for the Department of Defense, it all was um, serendipitous and I kind of fell into it, and to a great extent it's because I didn't know any better… it was all mistakes, happy mistakes, it was completely unplanned).* An early "mistake" occurred when he picked up the oboe in place of the bassoon, responding to a call by the city orchestra conductor looking for a bassoon player. Forgetting the name of the instrument, Ethan signed up for an oboe *(so the next year I went down to sign up for an instrument, and I walked in and said, "I would like to sign up for the…." and I forgot the name of the instrument. So I said "oboe")*. Ethan's course of life has been affected also by the passing of his father during his youth *(I didn't have a father that was saying "you should do this and maybe you should learn this"... these circumstances and crazy coincidences and certain kind of desperation to get work that led me to certain things).*

At times it was hard for Ethan to integrate his work with practicing his music due to his dedication to work and the long hours he put in. When the work load eased, he would then take the time and play. Occasionally he would even have to turn down performance opportunities that came about *(I remember a time when I was invited to play up at the Marlboro music festival, a friend of mine said "why don't you come up"... probably 30 years ago, and I just couldn't do it. I didn't have the time).*

Despite the difficulty of integrating music with work, Ethan was aware of the many occasions playing his instrument made him feel better and more complete. Because of this, Ethan devised ways to bring his playing into his work world, in two ways. First, when he felt like playing his instrument during work, he would "dial up" pieces from memory and would be "playing virtually" *(sometimes I have a need to play something, and I just play it. and I feel much better for it afterwards, I feel very satisfied, very complete. So… I also do that in my mind, I can, I have memorized so many sonatas and concertos that I can dial up something if I'm stuck in the airport and there's nothing to do and I don't have a book and everything else, I can dial up a concerto or something that I've played… it can be quite joyful,* i*t's a very, it's a wonderful feeling).* He mostly "hears" the music in his mind rather than visualizes it *(it's there, it's in my mind, I just bring it out and I can…I can hear it and I can feel myself playing it... I can sometimes see the music but quite often I don't, no).* Ethan's ability to "play music" in his mind helped him memorize numerous musical compositions. Second, at age 20, he brought his cello to practice at the Wright-Patterson airfield while being bored at work *(I was working, but I didn't have a life, I was bored… and I said, "I'm going to learn the cello," It took me a long time to find a cello teacher in Dayton, Ohio but I found one, and I rented a cello, and I literally went out to the airfield and I would practice).* For three months while in Dayton, Ethan practiced the cello a couple of hours a day, and even took lessons. Although Ethan occasionally brought music to work by "dialing pieces on request" and practicing his cello in the airfield, he does not think about work while playing.

Throughout his life, Ethan experienced situations in which his music practice has informed his cognitive abilities. He thinks music practice has enhanced his memorization abilities, visualization skills, abstraction skills, parallel thinking, analytical skills, confidence, and risk taking abilities.

When Ethan sings on Sunday evenings at the Harvard Square church he doesn't need to look at his score *(I pretty much memorize the piece, after two or three readings… pretty much am not* *looking at it when I'm singing… I have it in front of me but it's like a guidepost.)* The same goes for when he plays his oboe and cello *(I very often prefer to memorize the music because then I can spend more time on, on articulating the fingerings and things like that).* The organizational aspects of music compositions, such as the introduction of a theme and its development and recapitulation enhanced Ethan's memorization skills *(for me, it's to memorize certain road marks, landmarks, and then the stuff in between).* He is proud of his children who memorized Latvian poems at their Sunday Latvian school because he feels memorization, an important practice, has become a lost art.

Through playing his instrument and reading music, Ethan believes he has developed his visual memory as he was transitioning from the graphical to the performing side of music. He recalls an oral exam as a graduate student in which he was able to recall mathematical formulas from pages he skimmed through the night before that he would not remember otherwise *(they asked me a question from this section, so I'm standing at the blackboard under intense pressure, and what I'm seeing is the pages, I am seeing this two dimensional stuff with a lot of equations, and I'm drawing these equations on the board… I'm using this to solve this theorem, and when I walked in, I scored, so when I walk out of there I said, "where the hell did that come from?" I mean I just glanced this stuff, I was tired, I said, "that's from all those years of memorization, music memorization, that you have this way of storing graphic images–it's there, sometimes you don't even know it except when you have to pull it out.").*

Ethan's abstraction skills have been developed through his music playing as well *(an abstraction that I've learned from music… it's the balance of seeing the material and then taking it into the performance).* He utilizes his abstraction skills for building general-purpose software, which takes numerous rounds of iterations to write, as opposed to ad-hoc programs that are written instantaneously but often break down when used outside of their specific purpose.

For Ethan, music, unlike spelling and grade school mathematics, feels like a highly parallel process *(music is completely different, it's a very parallel thing, you've got um, you've got the printed material, which very often is multi-dimensional, it's got a representation of the reader, and the pitch, and articulations, and maybe other things, and then you have the instrument you're dealing with at the same time, you're learning how to control it and how to make sounds with it, so a lot of things are popping up at the same time)*. This parallelism has informed Ethan's parallel-thinking training, especially with his recent encounter with the cello *(I have four strings, and you can sound a note on several different strings the same note, it has different hammers, the hand is shifting around unlike a woodwind where the hand is fixed, the bow is moving, back and different places away from the bridge depending on what kind of sound you want to make).* Listening to his music while playing *(having to control things and feedback as well, lots of feedback),* has also enhanced Ethan's parallel-thinking capability, training him to simultaneously perform a task and process the immediate feedback it entails. This is analogous to the new generation of doctors who practice, for example, laparoscopic surgery with video game-like simulation–they are very good at performing, as they simultaneously manipulate data and feedback, while the older doctors can't do it.

As a player of multiple instruments, Ethan finds himself making analogies across his instruments, especially from the oboe to his recent instrument, the cello *(very often I breathe out when I'm down bowing it and breathing in when I'm up bowing).* He finds himself doing interpolation from oboe music, which has only the soprano clef, to cello music, which has bass, tenor, and soprano clefs. As a result, he would sometimes get confused with the fingering on the cello.

Performing in front of an audience has taught Ethan to be fearless *(I think performing teaches you to be fearless in a certain kind of way… Um, for me and when I perform, I may be, have some butterflies before the performance, but once I start playing I just feel confident).* It has also contributed to the confidence he needs to lead projects at work even when he does not have all the knowledge and solutions. His fearlessness combined with his problem-solving perspective gained him a reputation of someone who can dive into urgent and strange projects. On one such project, the Navy submarine project, his team managed a last-minute save of the jet of a satellite that was going to be put on orbit but had exhausted itself by tumbling forever.

As a young engineer, it was Ethan's desire to be a sole contributor on software projects, following the typical ego of programmers.[112] Only when becoming a manager of software projects, although not his choice, he began to appreciate the value of collaboration *(then I understood that there's a value to management, and how you coordinate people and that some things are much bigger than one).* It is here where he applied his orchestral experience *(how you work through things... how you coordinate people and how you leverage their strengths).* He still enjoys his solo performances, but recently prefers chamber music *(I like to play sonatas where it's the piano and a cello, or um I love string quintet work).* Playing in an orchestra for him is a bigger challenge than solo playing *(you have to be very well coordinated with everyone else, everyone's doing their thing, you have to get in there at the right time and do the right thing),* much like managing people on software projects.

[112] The tendency of programmers to work on their own, not considering other's ideas and being defensive about accepting criticism.

A similar sense of gratification that Ethan feels on stage he also feels when he programs *(there's this wonderful direct feedback that's very gratifying… Yes, you're experiencing at the moment, and software can be like that too, except that the value of um, these small programs, the gratification only lasts a short amount of time. As you get into larger solutions in software, they take longer, there's a gratification when you, you've created a product or something, and you go out in the real world and see people using it, they're balancing their checkbooks or they're, whatever it is, you know the rocket hits the moon, a lot of satisfaction).*

Ethan learns and thinks in a structured fashion, associating his thinking with the thinking style of British astronomer Frederick William Herschel, an oboist, cellist, organist and composer, who was inspired by music when reading star patterns and discovering Uranus *(he read the star patterns as all music)*. Ethan's knowledge of structures in music has informed his planning and organizational skills when developing large software programs. When he learns a piece of music he typically first identifies a general gestalt and then learns its detail *(you have a general gestalt, there's this piece, there's three movements, the first one's got this theme in it and then it starts out like this, and you just learn the general and you learn how to move down to the specifics).* He describes a similar process when managing software *(in managing software, I learned over the years as an executive, you plan extensively… I'm the type that takes the planning down to, I call it the build level, where everyone knows what they're going to do, and the way I plan it, is I bring a whole team in, and they hate it, they just hate it, and I say, ok were going to do such and such thing, and we start going over what we're going to do… we go through with this intense planning period, it might be a week, it might be three months… and I call that the dress rehearsal).* Ethan believes that his gestalt way of learning evolved from music and subsequently carried over to his work as a computer scientist, becoming his general way of thinking and learning.

Ethan enjoys reading music scores in bed, in the same way people take books to bed *(there's a certain joy in doing that because you can peek over the music, Ah, you can go back and forth on a couple of measures and really peek through it and really um, get a wonderful understanding of what's going on there).* Reading music scores has been helpful for Ethan in performing as it often reveals musical structures that would not materialize while playing *(recently there's been a cello sonata that I did, by a Russian, his name is Myaskovsky… he has this sonata that he wrote that has these wonderful things in it, one of them is that he, he has the melody playing along, and underneath it is this inverted sixth, parallel six being played, sometimes by the piano, sometimes by the piano and the cello, and the piano doing the melody, and what it does is, it kind of cradles the melody, and suspends what key it's in, it's like this melody is floating but you can't–it's quite magical the way it's done… it's a beautiful music but you can't quite figure out what the meter is, you know, it kind of suspends it. I read through it at first, and I was just kind of picking through all of this, and when you're lying there at night and looking at this, you can really spend a lot of time just looking at the notes and understanding the relationships that if you just sat down and played it, you might not…).*

Ethan feels that human brains have a scientific and artistic side, and that some artistic disciplines can be viewed as scientific and vice versa. Music is one of them. He even inspired a physicist colleague at MIT, who had simplistic views of music, to take music lessons by comparing music to physics in that they are both effective only when they are easy to understand. Ethan also recalls a Dilbert comic of a person working desperately on some mechanical device *(I'm trying to fix this thing and I don't quite understand how to do it),* who is approached by a dog, Dogbert, suggesting to the man to use his other side of the brain *("well use the other side of your brain, be creative")*. The man, who starts crying after accepting the dog's advice, responds to the dog when approached again *("now what's wrong?")*, saying that now he feels emotional about not being able to fix it *("I still can't fix it but now I feel really bad about it")* (See Figure 13). Ethan believes there are phenomena that can be understood only in one side of the brain but music is not one of them *(music can help you hone those skills that are hard to describe analytically).*

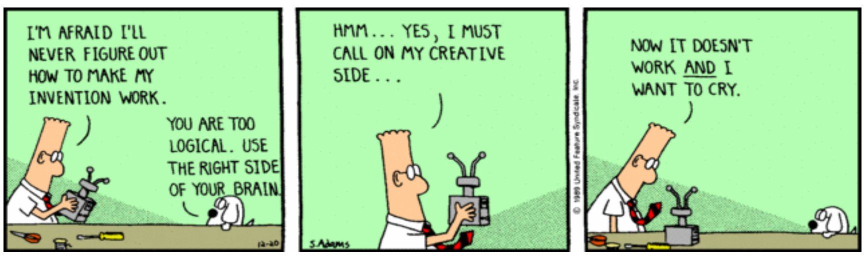

Figure 13: Dilbert by Scott Adams, December 20, 1989.

Playing his instruments can be a deep, spiritual experience for Ethan. He refers to his inspiring the physics professor to take music lessons *(it's very important to me in many ways, and ah, I think that I, it helps me pull things from the other side…).*

In summary, the main ideas in Ethan's story are:

- Reads music scores and thus reveals structures that are not recognized when played;
- Believes in artistic and scientific sides of the brain;
- Knowledge of structures in music informs planning and organizational skills when developing large software programs;
- Exposed to many cultures and languages;
- Played several instruments (oboe, cello, piano, cor anglais);
- Parents supported but did not push;
- Played as a child in numerous school bands and orchestras;
- Experiencing empowerment and gratification at early stage of playing and performing with musical groups;
- Slide ruler triggered mathematical interest;
- Early love and interest in trigonometry;
- Tentative idea of becoming a musician;
- Interested in both music and math already in high school (took courses in both and in Greek and languages);

- Playing makes Ethan feel better and more complete;
- Obtained several degrees (BA and two MAs) with no formal degree in music;
- Used music for moneymaking for a while;
- Likes to build things (model airplanes);
- Capable of "dialing up" music whenever felt like (e.g., at work);
- Music practice has enhanced his memorization abilities, abstraction skills, confidence and risk-taking abilities, visualization skills;
- From music, learnt to think at work with immediate feedback;
- Similar kind of internal gratification when writing a program as when performing on stage;
- Organizational aspects of music compositions, such as the introduction of a theme and its development and recapitulation enhanced Ethan's memorization skills also at work;
- Playing and reading music developed Ethan's visual memory at work;
- Combines music with work (practices the cello at work);
- Likes to think in gestalt mode first, and then looks at the details;
- Abstraction skills have been sharpened through practicing his musical instruments;
- Music, being a highly parallel process informed Ethan's parallel-thinking training at work;
- Making analogies across instruments;
- Music performance has taught Ethan fearlessness, which carried on to his risk taking at work;
- Orchestral experience helped in team work as a computer scientist;
- Feels similar type of gratification when playing and when writing programs;
- Music is a deep, spiritual experience (helps pull things from the "other side").

V. Chapter Five: Thematic Analysis

In this chapter, I present my findings of the themes that emerged from the analysis of the narratives of musical computer-scientists. As described in Chapter three on methodology, I've identified these themes by using a three-step process of analysis: conceptually grouping common ideas that appeared across these narratives, applying narrative and occasional sociolinguistic analysis to the narrative segments associated with these conceptual groupings, and applying relevant research theories to the results of the analysis. Following this process, I have assembled the following three primary themes, which are further divided and discussed along with their sub-themes in subsequent sections:

1. The meaning of playing and performing with musical groups;
2. Related thinking skills between music and computer-science disciplines;
3. Combining music and computer-science disciplines.

A. The Meaning of Playing and Performing with Musical Groups

In this section, I uncover the meaning of participating in musical groups for musical computer-scientists in my study. These individuals have participated in musical groups throughout their lives, continuously as well as periodically, in parallel to their work as computer scientists. They joined public school orchestras, bands, and local youth orchestras, often proceeded with musical groups in college, and later on joined community orchestras, chamber groups, and associations for amateur players. Such avocational participation in musical groups, referred to by Stebbins (2004) as serious leisure, has been found to be associated with perseverance, potential of career development, personal effort based on skills and practice, associations with unique culture, and distinctive identity. It has been associated also with personal rewards (e.g., self-fulfillment, self-enrichment, self-expression, renewal of self, enhancement of self-image, sense of belonging, self-gratification) and social rewards (e.g., association with other participants, group accomplishments, contribution to the development of the group).

Using the same three-step analysis process mentioned above, I have identified the following sub-themes that make up the meaning of musical groups, some of which align with the above aspects and rewards that Stebbins (2004) associates with serious leisure:

- Inspired, aspired, and self-motivated to achieve through perseverance;
- Social world;
- Visibility through musical performances;
- Bonding with family members and friends;
- Sense of gratification;
- Facilitating work.

1. Inspired, Aspired and Motivated: Persevering to Achieve

Players were inspired by their group counterparts or known musicians whom they encountered through their music group activities. They often aspired to reach their role models' quality of music or learn other instruments, becoming self-motivated to achieve their aspirations through persevering in their practice.

Ernie was unhappy when placed at the lowest clarinetist position in his public school orchestra *(I was third clarinetist… that's where you stick the people who don't know how to play their instruments very well… here I was just playing these real simple… lower parts)* (Ernie, personal communication, February 16, 2011). Inspired by the technical abilities and sound quality of the more experienced clarinetists *(I remember looking at the first clarinet players, who were moving their fingers really fast and they can play all these high notes),* he aspired to improve *(I thought, "wow that's very impressive, I wonder how they're doing all that?"… I kind of just had this goal to wanting to be able to play like them)* (Ernie, personal communication, February 16, 2011). Working to achieve his goal *(I was pretty motivated),* Ernie moved up the orchestra ranks and became first clarinetist by the end of eighth grade (Ernie, personal communication, February 16, 2011).

His self-motivation also persisted during his GBYSO preparatory camp, observing known performers, eventually advancing to become a principal clarinetist and even a soloist *(that was the first time I got to see all these players on a completely different level… it's the top players in all of Massachusetts… I realized I had a long way to go)* (Ernie, personal communication, February 16, 2011). Driven by his aspirations, Ernie especially appreciated the rotation experience at GBYSO, which enabled young players to experience different parts for their instrument *(it's nice cause they rotate around, they switch, so everyone gets to do different things)* (Ernie, personal communication, February 16, 2011).

Ernie's music quality was also inspired by the coaching he received from known musicians during his six years with MIT's musical groups *(MIT was fabulous for music, I think I developed musically quite a lot, Um, I played a huge amount of chamber music)* (Ernie, personal communication, February 16, 2011). He played with pianist David Deveau, French horn player Jean Rife, John Harbison who coached Ernie for the Brahms clarinet quintet, and Marcus Thompson *(we played just a lot of pieces at MIT with some great coaches… really great coaches, um and I think that did a lot for my, my music playing)* (Ernie, personal communication, February 16, 2011). Given Ernie's intrinsic aspirations to reach higher levels of music performance, there is no question that MIT's music environment provided him with an abundance of such goals toward which he could work and develop his music skills.

Ernie's narratives on his early participation in musical groups exhibit the salient theme of musical skill development through self-challenge and strong sense of agency, consisting of four elements: frustration with low performance relative to other group members, aspirations to reach superior performance levels, self-motivation to achieve these superior performance levels, and achieving aspirations through practice and perseverance.

Ernie positions himself as agentive in setting up his own challenging aspirations within his music-making leisure activity. He explicates his intrinsic motivation by his need to stretch his ability to the best of his potential *(but there was always looking to see other players playing and see how good they were or being inspired by that,* so *I don't know if I felt competitive or just motivated by that… it was always important to me to be playing… as best as possible… just kind of this quality thing, if you're going to do something, might as well do it the best you can)* (Ernie, personal communication, February 16, 2011). Ernie's family's status as new immigrants to the US may explicate his strong sense of agency and urge to succeed.

In their study of motivation, Ryan and Deci (2000) differentiate between autonomous (intrinsic) and controlled (extrinsic) motivation based on the degree of autonomy involved. When people are autonomously motivated, they experience self-endorsement of their actions. This is contrasted with controlled motivation in which one's behavior is a function of external contingencies of reward or punishment, or if one's action is energized by factors such as an approval motive, avoidance of shame, contingent self-esteem, and ego-involvements. In the context of aspirations, intrinsic aspirations include such life goals as personal development and creativity, whereas extrinsic aspirations include such goals as wealth, fame, and attractiveness.

Some studies (Vansteenkiste, Simons, Lens, Sheldon, and Deci, 2004) revealed that an emphasis on intrinsic goals, compared with extrinsic ones, is associated with greater health, well-being, performance, and with improved learning skills, (i.e., deeper processing of learning material, greater conceptual understanding, and persistence at relevant learning tasks). It seems that intrinsic-goal setting induces a quality of engagement and motivation with respect to learning that is different from what is induced by an extrinsic-goal setting. It is therefore likely that Ernie's intrinsic leisure-aspirations are related to his being a persistent and avid learner, as well as a creative person.

Ethan, who observed the drummers during concerts he attended with his mother at the young age of three, was inspired to become a percussionist at age seven *(I saw the band concerts and I saw the drummers, and I thought that was just, the greatest thing and I really wanted to play the drums)* (Ethan, personal communication, February 21, 2011). Later on, after observing the drummers' parts in classical orchestra concerts, he picked up the oboe *(a drummer's life is counting. If you look at a drummer in a symphony orchestra, most of the time it looks like they're polishing their cymbals or they're buffing their nails… and that wasn't something I was interested in)* (Ethan, personal communication, February 21, 2011). Always self-motivated with respect to his music playing, Ethan was inspired by the musical atmosphere in his multicultural hometown of Brockton *(I never felt like my parents, for example, were saying, "you should keep doing this," because I was so self-motivated, um I know they were proud of me when they came to concerts and things like that, but I think I had the motivation… I was encouraged because there was such a strong sense of the population in the city I grew up in, that music was an important thing)* (Ethan, personal communication, February 21, 2011).

Ethan, playing as an oboist with the Rhode Island Philharmonic at age 18, was also inspired to pick up the cello as he happened to closely watch from his seat a well-known, visiting cellist, Leonard Rose, from the Curtis Institute in Philadelphia *(we had a very famous cello player come, who sat right in front of me and played cello. He came actually two times, one time he played Dvorak Cello Concerto, and another time he came he played the, the ah, Rococo variations by Tchaikovsky and Rococo theme, both beautiful pieces… I said, "this is a really beautiful instrument and someday I'm going to take it up*"*)* (Ethan, personal communication, February 21, 2011). Two years later, bored while on an extended work assignment at the Wright-Patterson Air Force base in Dayton, Ohio *(people aren't, they just don't do a lot, they like to go to car races, and stuff I wasn't interested in… I could find people I could talk with)* relative to the rich cultural life in Cambridge *(there's a life, it's intellectual, there's books*), he decided to pick up the cello *(and I said, "I'm going to learn the cello")* (Ethan, personal communication, February 21, 2011). He found a teacher, rented a cello, and began practicing in the airfield *(I literally went out to the airfield and I would practice… I would practice a couple hours a day)* (Ethan, personal communication, February 21, 2011). Although he abandoned the cello after two years due to his busy life schedule, he vowed to pick it up in the future, which he did, after selling his last startup company. Ethan finds himself more analytical with respect to the cello compared to the oboe, attributing it to taking up the cello as an adult *(I hit it more analytically… you can sound a note on several different strings the same note… the hand is shifting around unlike a woodwind where the hand is fixed… I find myself trying… to make an analogue to the oboe, very often I breathe out when I'm down bowing it and breathing in when I'm up bowing)* (Ethan, personal communication, February 21, 2011). He enjoys playing sonatas for cello and piano, and even reads them in bed.

Like Ernie, Ethan, too, setup challenging musical goals during his orchestral career, and was intrinsically motivated to achieve them. However, unlike Ernie whose musical goals were planned and focused on one instrument, Ethan's were spontaneous and diverse, taking up multiple instruments like the drums, oboe (coincidentally), piano, bassoon, cor anglais, and later on singing in church, and the cello.

Stan, a percussionist, met through his musical groups several known musicians. While at GBYSO, He played with known American composer John Adams, whom he did not know of at that time, *(he played the Mozart concerto in one of the concerts. Um, so that was a big treat being in the symphony)* (Stan, personal communication, February 17, 2011). While playing with the Brookline Civic Symphony, Stan became acquainted with its conductor, Harry Ellis Dickson, who at that time played as first violinist with the Boston Symphony Orchestra, and later also conducted the Boston Pops. Participating in the Alea II music group at Stanford, Stan was introduced to another percussionist from the music faculty *(he was always asking me math questions, about Fourier series)*, whom Stan later found out was John Chowning, the inventor of the mathematics behind the synthesizer (Stan, personal communication, February 17, 2011).

One of Miro's important musical outlets was Tanglewood, where he played as a percussionist during the summers, and was inspired to study music in college *(I knew that, well first of all I wanted to go back for another summer, and that I wanted to study music at BU)* (Miro, personal communication, March 17, 2011). He was featured by a local paper, telling his story as a music student from western Massachusetts, along with a photo showing him playing with known musicians from the Tanglewood percussion ensemble. Through Tanglewood, Miro met many known musicians who later on coached him at BU, including Thomas Jaeger, a percussionist in the Boston Symphony, and violinist, Roman Totenberg *(I enjoyed what they'd been doing at*

Tanglewood and so on, so I knew I'd enjoy a lot of the same teachers. I knew that I'd enjoy what was going on at BU) (Miro, personal communication, March 17, 2011).

In addition to encountering known musicians, Miro was also inspired by his band director to play a multitude of instruments, also picking up the sousaphone[113] and the tuba *(the band director… he taught all the instruments… he taught people to play the clarinet and the tuba, and the piccolo, and the flute, and the drums, and the xylophone… so he taught me to, to play the tuba, the sousaphone)* (Miro, personal communication, March 17, 2011).

Playing the flute part of Bach's "Musical Offering," Meg successfully accomplished her musical goal to audition for her idol musician, Robert Koch[114] *(he was the person I wanted to play with, you know the most)*, with whom she then played and performed in various chamber groups for the next 20 years *(I even remember very vividly what I was wearing and everything. My husband came along and so we played this thing. He absolutely fell in love with me)* (Meg, personal communication, April 2, 2011). In describing her relationships with her coach, Meg positions him as her life support upon which she feeds *(so that was the reason why the Robert Koff connection was really kind of nutritional for me in terms of music, because I just enjoyed so much playing with him. He was just so fantastic)* (Meg, personal communication, April 2, 2011).

A "petting zoo" day for instruments, organized by the school's band director, enabled Meg, then a fourth grader, to narrow down her choices to the flute and oboe, finally going with the flute as she was too young for the oboe *(he sort of showed me what to do, and I picked it up and I made a sound right away. And he said, "no one can do that, this is what you ought to play.")* (Meg, personal communication, April 2, 2011). Although she was contemplating switching to the

[113] A tuba wrapped around the body.

[114] Robert Koch was a founding member and second violinist of the Juilliard String Quartet, and head of Brandies University's music department in the early 60s.

oboe, her desired instrument, she never did *(I got good enough that it seemed like what I should do)* (Meg, personal communication, April 2, 2011).

Although Delia did not participate as a pianist in chamber music groups in her youth, she joined a community music group while in her 50s, just two years after she picked up her new instrument, the clarinet. With her typical and ongoing appetite for experiencing new things *(I'm not the one that is focused on a subject. I like to all the time study new, new things that interest me)*, and with more free time available in her life, Delia began studying the clarinet *(a few years later they opened, this conservatorium, and my children were more grown up… so I found a time for myself, and I decided this is a good eh, idea to come back to the music. I decided this time I will try to play the clarinet)* (Delia, personal communication, May 5, 2011). Inspired by her clarinet teacher who led Eve's Women, an all female band, and suspending her clarinet lessons after her teacher had to quit *(she is a very good clarinetist. She's also a pianist, a drummer… she was quite a good teacher),* Delia joined a community music group *(they opened a group of grownups, amateurs, to play together…. it's not a regular group. We have two flutes, one violinist, three clarinet players, one saxophone player, one horn, and a pianist, and I am one of the three clarinets. Sometimes I'm also doing the piano)* (Delia, personal communication, May 5, 2011). Although quite casual about her recent musical group adventure, Delia's joining a musical group as a relatively new clarinetist reflects on her curiosity, courage, intrinsic motivation, and perseverance *(I like to, all the time study new, new things that interest me, and clarinet is new spirit, new thing, so it was exciting)* (Delia, personal communication, May 5, 2011). She is self-reflexive about her intrinsic motivation to play the clarinet in a group *(it's good for my soul… there is something that I'm doing for myself, and music is naturally a good, a good thing to do* *for yourself… the fact that I'm involved in music and doing something new, is giving me a lot of satisfaction)* (Delia, personal communication, May 5, 2011).

Overall, participation in musical groups provided their members with a context in which they were inspired, and in which they intrinsically aspired to develop their musical skills through hard work and perseverance.

2. Social World

One of the qualities of serious leisure, like music-making, is the unique culture that grows up around it as a special, social world (Stebbins, 2004). In fact, in defining the social network of amateur musicians in an orchestra, Stebbins (1976) has concluded that the interpersonal ties that emerge through such musical social networks have significant meanings to the amateur musicians, often exceeding their common purpose of making music.

In analyzing their narratives, the following sub-themes emerged as associated with the social world created by musical computer-scientists through their musical groups:

- Creation, preservation and renewal of friendships (corresponds to Stebbins' (2004) social reward of association with other participants);
- Sense of belonging and of boosting self-image (two of Stebbins' (2004) personal rewards);
- Connecting with the "other" through removal of social and cultural boundaries.

Close friendships were created between Ernie and his peers while playing six years of chamber music at MIT, to the point where they even formed their own music ensembles during summer breaks *(we would form our own kind of impromptu groups during the summer time with a group of friends who all got to know each other. We became really good friends and played* *music together)* (Ernie personal communication, February 16, 2011). Ernie also performed for special events in his friends' lives like their weddings *(these transcriptions of the Bach cello suites for the clarinet, Uh and I played a couple of them here and there like one for a wedding for my friend)* (Ernie personal communication, February 16, 2011).

At Tanglewood, Miro met students that later enrolled with him at BU *(many of them are professional musicians)*, becoming close friends with one of them in particular, a violist who practiced eight hours daily, whom Miro accompanied on the piano and shared a room with, now the principle violist of the Chicago Symphony Orchestra. Miro also accompanied his BU roommate at his BU graduation cello recital *(I accompanied him through his entire recital)*, as well as made his roommate play the Beethoven cello sonatas with him at his own graduation recital.

Stan, too, in his present band has encountered a person he knew from GBYSO and worked with at DEC, and befriended the Dean of Olin college, a mathematician and member of the orchestra too.

In addition to making new friends, music groups also offered Stan a feeling of social belonging. He found music ensembles to be his main social outlet during high school, where he associated with people who shared similar interests *(it was something social in high school I could be excited about, it was a, a community)* (Stan, personal communication, February 1, 2011). This sense of community through group playing continued in his undergraduate and graduate years. As an undergraduate at Tufts, he used to play the recorder with some of his professors including his department head *(it was very casual, you know, we knew each other by first names… he actually taught my first real analysis course… the department was, well it wasn't very small but people just knew each other, ya, we'd go to his house, and I'm trying to* *remember if my advisor played)* (Stan, personal communication, February 17, 2011). As a graduate student at Stanford, Stan picked up the recorder again and took an early music course specifically to join his colleagues and friends in their casual baroque recorder ensemble *(so we used to play, noon time, several days a week, just go out in the, in the court yard and play um, early music on recorder, four or five of us… this was very ad hoc)* (Stan, personal communication, February 17, 2011). Through playing in this and additional ensembles like the Stanford Orchestra and Alea II, Stan became involved with people from the music department, eventually advising one of their faculty members on math.

Meg's ensemble experience gave her, too, a strong sense of belonging, and also boosted her self-image *(it just was really like "wow I really fit in here." You know, and it was such a strong visceral sense of "oh I belong here" that I had not felt, you know, very much of, you know, otherwise)* (Meg, personal communication, April 2, 2011). As a shy and socially awkward child *(I probably have Aspergers… I'm just very fluent, you know, I just speak very well so I can disguise it. So I don't have many social clues),* Meg's band performance was her primary means of connecting with the rest of the world (Meg, personal communication, April 2, 2011). It made her feel more socially accepted, especially during her junior high and high school years, the typical period of searching for identity *(it was like the music could really sort of do my talking for me… that could be my means to fit into, to participate, to be part of something… it was sort of that sense of belonging… just a great thrill ah to do that)* (Meg, personal communication, April 2, 2011). Meg also believes these feelings of social belonging were particularly helpful to her as she grew up mostly in a discriminating, mid-southern culture *(where girls really were not supposed to be good at math)* (Meg, personal communication, April 2, 2011).

Delia’s weekly rehearsals with her community ensemble are a special social event for her. She enjoys getting together to play with other amateur adult players, in contrast to her solitary piano playing in the past *(the fact that you’re doing it in a group is much more, it is much more fun I think, the harmony… it’s also eh, some kind of em, social event)* (Delia, personal communication, May 5, 2011).

Although not actively playing in music ensembles, Sol, a pianist, has been socially involved with chamber music players through the chamber music concerts he organizes with his wife at their home in California *(that’s taken a good deal of my time, just organizing that and arranging that and dealing with other musicians… we’ve gotten to know a lot of musicians)* (Sol, personal communication, February 28, 2011).

Playing in a musical group enables connecting with people who are perceived as different. At his ensemble rehearsals, Ernie enjoys meeting people who are mostly full-time musicians and appear to him more relaxed *(it's a different group of people than at work. So it's nice having those two different, you know different groups of people to be able to interact with in different ways… almost most of the people I play with are just, are musicians. They don’t necessarily do other things… they come from a different place. They probably have different perspectives. I usually find that they’re um, they’re a little more relaxed I think. I mean there’s … not that it can be stressful to be a musician as well)* (Ernie, personal communication, February 16, 2011).

Perceiving his close BBN work colleagues as not particularly knowledgeable about music in the technical sense *(I'm sure they have their own taste in music, but not as practitioners),* Stan, too, enjoys getting to meet people he perceives as different at his Concord community band *(one thing I like is that it's a different group of people, from work)* (Stan, personal communication, February 17, 2011). He prefers to keep music separate from work as for him the music world represents a separate social world than the social world around his work *(typically in my life, music has been sort of separate social scene… it's another life (laughs). It's not that the music is different, it's just that, it's, it's another social, another part of my social interaction, which is separate, well it's nice having more than one, one thing to do)* (Stan, personal communication, February 17, 2011). Indeed, also during his undergraduate and graduate years, he tried as much as possible to keep his social circle of friends, with whom he took math and physics classes, separate from the people he knew from the music department *(there was some overlap, but not a lot so I sort of had two social circles, and same at Stanford)* (Stan, personal communication, February 17, 2011). Nowadays, however, Stan's weekly participation with the Concord band is less social than his frequent associations with music groups as a student, because of everybody's work duties and family obligations *(people come from work, and practice, and then, it's less social, you know, every so often we have get-togethers, but over the years you get to sort of know them, but not really)* (Stan, personal communication, February 17, 2011).

Participants also report that geographical, cultural, and ethnic boundaries dissolve when playing music together. While on tour with her youth symphony orchestra to Europe, as part of an International Youth Symphony Orchestra festival during the Iron Curtain era, Meg, a flutist, befriended two young Czech orchestra players *(I could speak German and French a little, so we kind of got, we were able to communicate, and I had a pen pal for years after that)* (Meg, personal communication, April 2, 2011). She was surprised to learn that foreign cultures can grow closer through playing together *(it was really neat to kind of have that opportunity to, you know, meet people from what seemed like a really foreign culture and yet we found out, you know, it's like, oh music is a universal language. We had no problem getting together and concertizing)* (Meg, personal communication, April 2, 2011). While touring with her youth symphony to the University of the South *(they had a phenomenal summer orchestra and chamber music),* Meg also befriended African-American students, which was unusual for her in Virginia at that time *(but that was just an enormous, kind of cultural change… it was the first time ever that I had friends that were black. You know, they had a phenomenal black violinist… I rode on the bus with plenty of black people in Washington D.C., but there was no way you were going to speak to one, they certainly were not in your school, you know, no way. Um, so I just thought that was the coolest thing. And my roommate was Japanese! And I was very close friends with her… so this was just really eye opening, and you know, just wonderful)* (Meg, personal communication, April 2, 2011).

Growing up in Brockton, Massachusetts in the 1940s and 50s, then a multicultural town with lots of immigrants *(I grew up with everybody)*, Ethan was given the opportunity to engage with kids from multiple cultures, classes, and social backgrounds through musical groups (Ethan, personal communication, February 21, 2011). With the population's strong sense that music is important, almost everyone in the school system played an instrument and participated in musical groups through the town's music conservatory, independent of their background or musical competence *(almost all my friends played an instrument, even if it wasn't that good, it's just everyone played and it was understood. The parents were the same way, and there were a lot of musical groups… it was just ubiquitous where I grew up)* (Ethan, personal communication, February 21, 2011). Ethan even recalls rehearsals at the Brockton Symphony Orchestra being conducted in Yiddish *(I spoke enough German so I could remember what they were talking about)* (Ethan, personal communication, February 21, 2011).

Overall, this social world gave its participants the means to connect with people like colleagues and audiences, provided them with a sense of belonging that boosted their self-image, and granted them a multicultural lens. As adults, their participation in musical groups provided them with a social world in which they could dissociate from their social circles at school or work. This latter phenomenon can be explained by the work-leisure compensatory relations of contrast identified by Parker and Wilensky (Veal, 2004), in which work experiences are compensated for in a variety of unrelated, non-work activities.

3. Visibility through a Non-Competitive Environment

Visibility is neither a common phenomenon for the amateur solo performer, nor is it provided to the typical computer scientist at his or her competitive workplace. Periodic public performances provided young players, as well as adult musical computer-scientists, with visibility in their non-competitive environment of musical groups.

Miro, a pianist, is aware that his Carnegie Hall performance would not have happened if he had not teamed up with a flutist through the directory of the Chamber Music Network, ACMP *(playing chamber music, you can have more opportunities, I mean um, I got to play in Carnegie Hall… that was an opportunity that as a soloist I would have not even considered)* (Miro, personal communication, March 17, 2011). Offered an opportunity he couldn't pass, combined with his past experience in accompanying people as well as a couple of solo recitals, he went ahead with the concert *(first you say, "ok this opportunity is never going to happen again")*. This opportunity entailed more visibility for Miro than just the performance itself, as he also organized and participated with his flutist co-player in a complete concert tour in five cities prior to the Carnegie Hall performance, in addition to managing the recording, producing, and selling of their CDs (Miro, personal communication, March 17, 2011).

In addition, Miro, who confessed to not being a competitive person, found a safe haven with BPAA, an organization of amateur pianists. There he performed solo during their soirees, and also competed multiple times in their public amateur competitions, never getting beyond the preliminaries, however, *(some of the people play at a professional level. It's like all levels)* (Miro, personal communication, March 17, 2011). Once again, Parker and Wilensky's (Veal, 2004) compensatory work-leisure relations can explain Miro's interest in participating in musical groups and amateur competitions, especially with regard to visibility. As Miro attests, his software contributions as a computer scientist were not visible due to non-disclosure regulations of his workplace *(a lot of the stuff I've done, I can't really show off my work… it's under non-disclosure… the programs that I wrote, that the people in the company work with, are not intended to be seen outside… if I'd taken my spare time instead of practicing in my spare time, and um, you know done some work on open source software, I might have been able to point to something and say, "here's something I produced")* (Miro, personal communication, March 17, 2011). Given this business-visibility issue, along with his non-competitive personality and lack of leadership aspirations at work *(I wanted to be either an individual contributor working on a project all by myself, or working as member of a team but not leading the team)*, Miro likely enjoyed some visibility through his performances with amateur musical groups (Miro, personal communication, March 17, 2011).

Delia, performing with her adult music group as a clarinetist, feels relieved from the responsibilities she would have had as a solo pianist *(in a group, you know, other people sometimes cover on your mistakes, or, so it makes you feel more secured*) (Delia, personal communication, May 5, 2011). Typically a shy person at work who does not excel in public relations, sales, documentation or presentations *(sometimes it's very difficult for me to put my* *thoughts in words)*, she has lastly obtained the opportunity to perform in public performances and enjoy them *(it's quite nice I must say, this eh, I enjoy it)* (Delia, personal communication, May 5, 2011).

Meg, too, acknowledges the importance of participation and performing with music groups in her life, especially around junior high, compensating for her shyness and social awkwardness *(it was really kind of my thing in junior high, because I was very shy, and I was socially awkward… I remember just feeling such a sense of belonging, I had this… wonderful band teacher I told you about… it just was really like "wow I really fit in here"… I loved performing)* (Meg, personal communication, April 2, 2011). She also reflects on shy kids, like her son, who counter-intuitively excel in the performing arts *(it's very interesting to me that a lot of times really shy kids are great at drama and stuff. I mean my son, it's like you can barely get two words out of him, but he's a phenomenal singer and actor… that's his outlet and it's very typical, it's not an unusual thing to understand)* (Meg, personal communication, April 2, 2011).

Ernie did thrive on public performances throughout his life, beginning with his fascination as a young orchestra performer with Boston's Symphony Hall *(here I am, sitting in one of the most amazing orchestra halls in the world, you know, just kind of playing some notes, It was really, really amazing… you start thinking about all the amazing world class musicians who've been on this stage, and how they played, and Harold Wright was the principle clarinetist with the B.S.O. at the time, and you know I was thinking, "wow he gets to play here all the time")* (Ernie, personal communication, February 16, 2011). Despite enjoying his performances, Ernie used to get nervous and had to overcome occasional memory slips *(I remember getting nervous for all these things… getting rid of the nerves is very difficult… it's actually getting better… I don't really play by heart)* (Ernie, personal communication, February 16, 2011). He acknowledges the effect frequent performances have on reducing his nervousness *(the more you play the more it helps, but it's a very slow process… you need to build up um, confidence and you need to build up good experiences… you play, and you might be a little nervous, but say it still went really well, and then you remember that, and now next time, if you can remember that, "actually it's ok, I know how to do this because… I'm feeling a little nervous but" you have to convince yourself that you're confident that you're able to do this)* (Ernie, personal communication, February 16, 2011).

Overall, through performances, auditions and occasional low-key competitions in the non-competitive environment of amateur musical groups, musical computer-scientists were given visibility opportunities they did not experience at work, either voluntarily or enforced. When younger, these visibility opportunities often compensated for their introverted character, awarding them with feelings of worthiness and self-confidence.

4. Bonding with Family Members

In addition to associating with group participants within the social world of their musical groups, study participants were also able to bond with their spouses and parents.

Meg met her husband, a well-known bassoonist and jazz player, through orchestra playing when they were both hired to play for the musical *A Chorus Line (in this one show we kind of landed together and that's, that's where we met, and kind of immediately, it was kind of like my fate)* (Meg, personal communication, April 2, 2011). Occasionally, Meg would also play with her husband *(we did some things together),* but not much, as he was not a classical-music player (Meg, personal communication, April 2, 2011). Meg and her husband also used to take their oldest daughter and friends to the shows they performed, like *Dreamgirls (she got to bring* *friends from school, boy she was really popular you know at school as a result… so she spent a lot of her time going with him to rehearsals as a little kid, so she had this really amazing relationship with him*) (Meg, personal communication, April 2, 2011).

Players also bonded with their parents through playing jointly. Meg felt special having her pianist mother accompany her at home and at her teacher's home *(that was really quite a big deal and he was very impressed she played so well, and that I got the opportunity that a lot of his other students didn't have, you know, of having somebody in the house who could, you know, being doing the, you know, the continuo with these pieces)* (Meg, personal communication, April 2, 2011).

Meg indirectly attributes her choice of flute as her instrument to her pianist mother who regretted not playing a portable orchestra instrument *(she said, it'd have been just so fun to play cello or violin or something so I could have played in an orchestra, and she often complained about, that's the trouble when you play piano … you can't bring your instrument with you…. I certainly heard that tape playing a lot)* (Meg, personal communication, April 2, 2011). Moreover, Meg's mother denied her daughter's wish to play the cello, as she considered it a masculine instrument. Thus, it is likely, that Meg's choice of the flute compensates for her mother's misfortune of not playing her desired instrument. Nagel (1987) explains such a phenomenon with object relation theory, in which certain objects are reacted to with feelings once developed toward some other definite person, like parents. According to this theory, the instrument, with its perceived power to nurture, reward, or punish, may reactivate the musician's feelings and experiences of earlier meaningful relations with his or her parents, and provide a link to his or her parents. As such, it is possible that through her performing the flute with musical groups, Meg has preserved her link with her mom.

Ernie, a clarinetist, who is married to a pianist, has performed with his wife, a scientist and a musician as well, in musical ensembles at MIT where they met. Recently, they also performed in the same concert in Rockport, where his former MIT mentor, a pianist, played Brahms's clarinet sonatas with Ernie and the Brahms Liebeslieder for four hands with Ernie's wife.

5. Feeling Gratified

Stebbins (2004) lists self-gratification, a combination of superficial enjoyment and deep satisfaction, as one of the personal rewards of serious leisure. Some study participants report on experiencing this type of gratification in both their music and work.

Ethan senses instant gratification when he plays music. As a music performer, he senses pleasure almost at the same time he creates music *(music makes me very happy and ah, and it can be a deeply spiritual experience sometimes too)* (Ethan, personal communication, February 21, 2011).

Ernie receives his self-gratification in music from the emotional aspect of music and from connecting with the audience during performances *(for music I think it's um, you know, emotionally it's very satisfying to be playing music… you can really connect with the listeners)* (Ernie, personal communication, February 16, 2011). Feeling gratified through his music performances was partly what drove Ernie to make progress in his clarinet playing *(I played clarinet for Fiddler on the Roof which has a fabulous clarinet part, you know, all the Klezmer clarinet stuff, right. So that was a really wonderful experience, I remember um, you know, getting assigned that and, an playing it and rehearsing it and it was just, just fabulous… I think I've always really enjoyed it and felt it was very gratifying and I've always wanted to improve and make myself better)* (Ernie, personal communication, February 16, 2011). His use of the words *"wonderful"* and *"fabulous"* along with the intensifier *"really"* denotes the degree of his satisfaction from performing. He uses the words *"always"* and *"since starting"* to indicate that playing has been part of his identity. He also hints to a kind of reciprocal relationship with music, in which the gratification makes him want to improve and get better, which then in turns provides more gratification.

Miro stresses that self-gratification in these disciplines cannot be awarded without investing in learning and practicing *(the fact that something to start with is difficult and you work at it, and you spend a lot of time working at it, and you get good at it, and it's enjoyable, and people enjoy what you're doing, that's basically the skill of discipline… it's the opposite of instant gratification)* (Miro, personal communication, March 17, 2011). He believes that starting music early as a child is important, so the child can acquire self-discipline early on *(the skill of being able to work at something, everyday, for a week, or two weeks or months, and then have something that nobody else can do what you can do)* (Miro, personal communication, March 17, 2011).

Miro's gratification from music performance resembles his gratification from programming as they both yield a concrete outcome resulting from coordination and execution of instructions *(arranging music for the orchestra is taking this process… giving a set of instructions for the orchestral musicians to follow, maybe with a conductor, maybe without a conductor, but if they all follow the instructions and listen to each other and everything like that, you get music out of it… it's just a wonderful thing to be able to play concerts, to play, so it's fun to get together for chamber music things. it's wonderful to put on a concert)* (Miro, personal communication, March 17, 2011).

Piano playing has been also Delia's mental savior *(its good for my soul),* and an activity she does for herself as opposed to for the benefit of others *(something that I'm doing for myself… the fact that I'm involved in music and doing something new, is giving me a lot of satisfaction)* (Delia, personal communication, May 5, 2011).

6. Informing the Computer-Science Workplace: Connecting, Collaborating, and Managing; Enhancing Confidence; Mindset Refresher

As computer scientists, some participants concur that their practice in the social world of musical groups, a sort of community of practice (Wenger, 1999), has occasionally contributed to their future practice in their computer-science communities. It honed their skills to connect and collaborate with people, and to better manage their teams and time, empowered them with communication skills, strengthened their confidence levels, and created a refreshing change of mindset.

a. Connecting, Collaborating, and Managing

For Ernie, learning how to work with players in one's music group, carried over to his workplace at Harmonix *(there's all these things that happen when you're playing music that, that you know you have to do when you're working in a professional environment)* (Ernie, personal communication, February 16, 2011). He feels that the two most important qualities that occur in both worlds are teaching oneself to always come prepared *(or else you're disappointing the other members of your group),* and learning how to deal with disagreements *(you need to get along, you need to understand how to resolve conflict if you have different interpretations for something… it's the same thing, conflict resolution is one of the most important things when* *you're in a professional work environment with other people)* (Ernie, personal communication, February 16, 2011).

For Ethan, orchestra playing presents a great challenge in terms of coordinating people *(you have to be very well coordinated with everyone else, everyone's doing their thing, you have to get in there at the right time and do the right thing)* (Ethan, personal communication, February 21, 2011). In his opinion, this resembles the challenge he typically faces of building large software projects *(that applies to managing people as well, software projects, it's very important, understanding how to coordinate people… there's nothing worse in a software project where everyone goes off and starts doing their own thing)* (Ethan, personal communication, February 21, 2011). As he outlines his steps when managing the development of large software projects, Ethan brings in the concept of an orchestra dress rehearsal *(I bring a whole team in… and I say, "ok were going to do such and such thing," and we start going over what we're going to do… by the time were done with the planning, things work so much better, we've got 80% of the problems resolved… Um, and I call that the dress rehearsal, we rehearse doing the project, multiple times)* (Ethan, personal communication, February 21, 2011).

Although not into management, Miro believes that playing with chamber groups facilitates collaboration with people *(some management skills do get honed when you're playing in chamber music)* (Miro, personal communication, February 21, 2011). Given his experience playing at ACMP, he believes that playing with random chamber music groups trains one to work with people with different levels of competency, like in the real world *(in management, you often deal with workers who, who work better, workers who don't work so well. Part of the task of a manager is to help a worker who is not working too well, to become better, and part of the task… more in a group that gets together regularly and performs, is helping each other to, to* *excel)* (Miro, personal communication, February 21, 2011). Miro also believes that being part of a chamber music group gets one to cooperate with people *(in the working world, you have to cooperate with people all the time)* (Miro, personal communication, February 21, 2011). For Miro, playing with random music groups in ACMP was an experience in learning to cope with the unknown, demanding spontaneity, readiness, and risk taking *(it's a little bit like you're thrown off the deep end… you say "I'm a pianist," and all these string players grab you, and ok, some wind players grab you because ok, we're doing this thing by, they pulled out something, I think it was an early Rimsky Korsakov that's for um, woodwind quartet plus piano… so there you are, sight-reading… spending about four hours sight-reading and just about every possible combination)* (Miro, personal communication, February 21, 2011).

The knowledge of how to connect with people at work comes to Meg partly through connecting with her audience and ensemble members *(it definitely had a huge influence… so the performance and the music-making, it's possible for me to understand what it meant to connect with other people,* connect *with an audience had been really important… I use that every single day… there's no question about that)* (Meg, personal communication, April 2, 2011).

Playing in musical groups while having a job sharpens time-management skills as it requires players to learn to navigate through their music practice, rehearsals, performances, and work deadlines. Ernie, who sometimes leaves work for midday rehearsals, needs to carefully manage his work day *(I can come in, I do two hours of work, you know, which is usually meetings or emails or whatever, um, then it's like "ok gotta go," take my clarinet, drive off to rehearsal… it takes about 10 minutes to get going… then we start working on the piece… and then after two hours I'm kind of packing up my instrument and going back to work)* (Ernie, personal communication, February 16, 2011). Similarly, he has a tight schedule that incorporates music practice into his work and family life prior to performances *(I have a routine which it pretty much works out with no margin for error… I wake up in the morning, make breakfast for the kids, um, Yukiko and I alternate, so I take a shower, so either I take one of them or the other to school, I come back home… I practice for an hour, pack everything up and I have 15 minutes to get into work by 10… and then I work and my days are completely non-stop till 6:30… if for some reason I didn't get to practice in the morning, I might practice at night)* (Ernie, personal communication, February 16, 2011).

Miro, in preparation for his duo recital at Carnegie Hall and the preceding concert tours, scheduled his vacation time far in advance and made sure to complete his work obligations *(I've never been in a situation where there's been a conflict because, like we're in crunch time… you're like devoting all your time because the thing has to be done by this time. You know, there's a deadline)* (Miro, personal communication, February 21, 2011). He feels that most workplaces he has worked for were supportive of his music endeavors *(most places you work now, Um people have kids, for instance, they're very supportive of time you spend with your kids. So, so a lot of places now … people are a lot more enlightened)* (Miro, personal communication, February 21, 2011).

Meg is aware of her effective presentation skills at work from compliments she receives or overhears from peers *("Meg is all about communication.")* (Meg, personal communication, April 2, 2011). She attributes the ease by which she acquired these skills to her numerous music performances *(it's easy for me because I've given thousands of public performances… there's no question that the, you know, the ability to have done many public performances has a tremendous affect on being able to communicate effectively… every time my parents complain* *about why do we pay all this money to NEC for you to get a music degree when you're not doing that, it was worth every dime)* (Meg, personal communication, April 2, 2011).

Advised about the need to always tailor her presentations to the present audience, Meg felt familiar with this advice from her own music performance experience *(well I know what that is, that's performing. You know if I'm performing a piece for kids I do it slightly differently, whatever. Or I'd program it differently)* (Meg, personal communication, April 2, 2011). She applies this advice to her current presentations at work on genomics *(a huge complex system and web of relationships),* that need to be understood not only by the scientists but also by business personnel *(I think that's certainly one of the big issues in genomics that I see, it's probably pretty ubiquitous in science in general)* (Meg, personal communication, April 2, 2011).

b. Enhancing Confidence

Stan's music performances have affected his presentations at work. Being nervous during public performances and managing to successfully overcome his nervousness, is a feeling Stan first encountered during his music performances *(the whole notion of getting nervous about something and getting through that, that probably first happened in musical situations)* (Stan, personal communication, February 17, 2011). Becoming familiar with this feeling, Stan carried it over to his presentations at work *(I just sort of felt, well I did that for that performance, I can do it for some other performance, and I need to do it, speaking, in my work. And so I, in music I sort of recognized the right degree of feeling nervous to make this work, so if you're too nervous, you can't play, and if you're not nervous enough, you can't play. So I can recognize that in music, and I can sort of now do that in other things, not as successfully because music is much more, constrained in a sense, so I'm, I'm better at music than at other things cause I know how nervous I should feel at a performance)* (Stan, personal communication, February 17, 2011).

Ethan, too, feels that music performing has taught him to be fearless *(for me and when I perform, I may be, have some butterflies before the performance, but once I start playing I just feel confident)* (Ethan, personal communication, February 21, 2011). That has helped him to become confident as a project leader *(well if you're going to lead a project you're going to need a certain amount of confidence if you don't know all the solutions)* (Ethan, personal communication, February 21, 2011).

c. Mindset Refresher

Stan finds his music rehearsal refreshing as it offers a different environment from work *(it's kind of nice, rehearsals are kind of this nice um time for me, where I'm doing things that are different than what I'm just doing at work… most of the people I play with… they might still have to have their jobs and still have to teach um and that kind of thing… they're still really excited about what they're playing and why they're playing it)* (Stan, personal communication, February 17, 2011).

Delia, too, feels that her playing with her community band allows her to interweave work with something different, as she has always enjoyed engaging in multiple activities *(I feel good when I do this mixture, not only work, work, work)* (Delia, personal communication, May 5, 2011).

Ernie describes his occasional midday rehearsal, prior to an upcoming concert. When that happens, he feels like diving into a different world for three hours of rehearsal, and coming back to work refreshed and charged *(it's really this kind of wonderful thing… I actually think of it as this nice, very different thing that I'm doing right in the middle of the day… take my clarinet, drive off to rehearsal, it's a completely different world… totally different mindset, totally different sense of time… it takes about 10 minutes to get going… then we start working on the* *piece… we get into it and actually working and focused on it, um, and then after two hours I'm kind of packing up my instrument and going back to work, but it was this period of something completely different, you know, in the middle of the day, which is, which I find kind of nice)* (Ernie, personal communication, February 16, 2011).

Also Meg acknowledges her being energized and delighted at work after a successful chamber music performance. Driving away from work for a special performance and demonstration to celebrate J.S. Bach's birthday, she felt transformed and returned to work energized and refreshed *(it was just a really fantastic like experience, where I felt, you know, completely transported… I came back to the job, and this was like an exhausting start up job, I mean I worked a billion hours a week, but I came back to the job and I felt more rested, it was as if I'd had a three week vacation at the beach)* (Meg, personal communication, April 2, 2011).

Overall, participation in music groups has provided musical computer-scientists with a non-competitive context in which they were self-motivated to persevere through practice, and were rewarded with a rich social network and enhanced self-confidence. It also informed their work habits, contributing to their collaboration and management skills. At the same time, it also enabled them to dissociate from their day-to-day social circles at work, and occasionally to recharge and retune their work mindset.

B. Related Thinking Skills in Music and Computer Science

In this section, I present aspects of thinking skills that musical computer-scientists in this study share across their computer-science work and while engaging in music, along with their significance for these individuals. I took to this task following the notion that thinking skills used by scientists are related to thinking skills used by musicians, and that science and music are two manifestations of common ways of thinking (Boettcher, Hahn and Shaw, 1994; Root-Bernstein, Bernstein, and Garnier, 1995; Root-Bernstein, 2001).

Using my three-step methodology of applying narrative and sociolinguistic analysis across narrative segments that share the same conceptual grouping, along with the application of cognitive theories, I have identified the following shared aspects of thinking skills:

- Being in the zone;
- Assuming an engineering mindset (emergence and expression of analytical mind through pattern-oriented and structural thinking, and spatial/visual[115] abilities);
- Aesthetic thinking.

Often, when individuals were not able to identify or speculate on the developmental pathways of a particular skill, I attempted to infer them using sociolinguistic analysis tools when possible.

1. Being in the Zone

While solving computer-science problems at work or when performing music, study participants reflect on being intensely motivated and focused at their activities, often describing this mental state as "being in the zone." Meg, Ethan, Ernie, and Miro relate their in the zone state when writing computer programs to a similar state while performing music. With their early music involvement, prior to their computer-science careers, it is highly likely that their mental state of being in the zone originated and developed primarily within the music discipline.

Meg, a flutist and a computer-systems architect, expresses feelings of being in the zone while performing and at work *(when I'm really engrossed in thinking about, you know, solving a*

[115] The ability to generate, retain, retrieve, and transform visual images. In this document I use the words "visual," "spatial," and "imaging" interchangeably.

computer-science problem, it's just the same when I was engrossed in a performance, and you kind of get in the zone) (Meg, personal communication, April 2, 2011). As indicated by the temporal markers *"I'm"* versus *"was,"* Meg juxtaposes her computer-science world against her music performance world, suggesting that reaching this mental state of being in the zone originated from her music performance world and then transferred to her computer-science world.

To further explicate her state of being in the zone, Meg brings up yet another discipline, the sports world of tennis, through *The Inner Game of Tennis*[116] (Gallwey, 1997), a book she read that theorizes about *(how people in sports get in the zone)* (Meg, personal communication, April 2, 2011). Recalling the book, she equates her being in the zone with the mental state of the tennis player during a match, almost like blocking out irrelevant thoughts and being hyper-focused, an intense form of mental concentration that focuses consciousness on a narrow subject *(it's like you're, you're just really, not exactly like blocking everything out, but it's just kind of like you're hyper-focused)* (Meg, personal communication, April 2, 2011). Meg's alternating use between the personal pronouns *"you" (you kind of get in the zone; it's like you're…blocking everything out; like you're hyper-focused)* and *"I" (I'm really engrossed in thinking; when I was engrossed in a performance)*, can be explained with *"you"* referring to a generic group of people, either the group of people who have been in this mental state or to the group of professional tennis players described in the book (Meg, personal communication, April 2, 2011). Schiffrin (1996) mentions a similar role for the pronoun "them" in her analysis of narratives about intermarriage, in which the deictic pronoun "them" within the phrase "she'd never go out with them again" refers to a generic group–the group of gentiles (Schiffrin, 1996, pp. 172-176). It is also possible that Meg

[116] The book theorizes that a tennis player maintains a zone of attention by never leaving the zone of four quadrants of attention that includes assessing, acting/reacting, analyzing, and rehearsing that lie along the two separate continuums of attention and body-concentration.

uses the pronoun *"you"* instead of *"I"* to make her discourse less personal when she describes an abstract state of being in the zone or "hyper-focused," as people who reach that state lose self-awareness. She is, however, more personal when speaking about the concrete actions that bring her to this state *(engrossed in a performance*, *engrossed in thinking about, you know, solving a computer-science problem)* (Meg, personal communication, April 2, 2011). Another possibility is that *"you"* refers to the interviewer, whom Meg wants to think is in her position and understands or shares her feelings.

These accounts of feeling hyper-focused and in the zone resemble the state of flow described by Csíkszentmihályi (1990). Reiterating his outline, reaching that state entails a high degree of absorption and focus on challenging activities, alignment of activity challenge with skill level, total control, loss of awareness of anything else going on but the activity at hand, and immediate feedback from the activities. This feeling of flow is an indicator of true enjoyment associated with the positive affect derived from invested attention, and is different from pleasure, a feeling derived from instant gratification.

Ethan, an oboist and computer scientist, also reaches the state of being in the zone while performing as well as when programming *(and also software is like that sometimes, um, there are times, when, if you're coding, times when you're in the zone)* (Ethan, personal communication, February 21, 2011). Like Meg, Ethan juxtaposes the computer-science world of programming with the music world. The "also" marker *(and also software)* implies that computer science was a follow-up discipline in which he also experienced flow, while the deictic pronoun "that" *(is like that)* points to the source discipline of music that is vividly depicted in the following segments from the subsequent mini-narrative *(when you're sitting on the stage*, *all that music is, is physically flowing through you, the vibrations are moving through you… and you are* *in a sea of people and you are all moving together and you're responding to each other… you're the music but you're responding, you're working together… it's a very powerful experience… it's at the moment, it's at the moment)* (Ethan, personal communication, February 21, 2011).

During this powerful stage experience*,* Ethan alludes to components of flow (Csíkszentmihályi, 1990): absorption in the activity *(all that music is, is physically flowing through you)*, loss of self-consciousness *(you are in a sea of people and you are all moving together and you're responding to each other)*, merge of activity with immediate feedback in the course of the activity *(you're the music but you're responding),* and his use of the buzzwords for flow *(it's at the moment, it's at the moment)* (Ethan, personal communication, February 21, 2011)*.* In addition, this state of flow is accompanied by bodily movements and sensations *(you're moving and the other people are moving… all that music is, is physically flowing through you, the vibrations, the sound… it's physically, the sound is so strong that um, the vibrations are moving through you)* (Ethan, personal communication, February 21, 2011)*.* Music performers often think through moving their body parts and through facial expressions, while scientists may think through manipulating their lab instruments and touching materials. This phenomenon of bodily thinking[117] has been identified by Gardner (1993) as kinesthetic intelligence, one of the multiple intelligences, enabling people endowed with such intelligence to learn more effectively through their physical experiences. It has also been identified as one of the 13 cognitive skills that distinguish creative people, including scientists and musicians (Root-Bernstein, R. and M., 2001). For example, some pianists memorize better through the motoric movements of their hands, rather than through the harmonic progressions of the musical piece.

[117] Thinking with the body is the automatic, unconscious and continuous movement of our body parts and visceral feeling that accompanies our thinking, which is most evident when we learn a new skill, and less so when the skill is mastered.

During his writing of code in a spontaneous rather than premeditated manner, Ethan reaches a state of flow similar to the one when performing music on stage *(there are times when, if you're coding, times when you're in the zone…)* (Ethan, personal communication, February 21, 2011). When in this state, Ethan also feels a loss of self-consciousness and immediate receipt of feedback from his code writing. His loss of self-consciousness is similar to an out-of-body[118] experience *(it's almost like an out of body experience… it's almost like–you're not ah, you're not doing it yourself, you're looking down on yourself and this stuff is just coming out and it's perfect)* (Ethan, personal communication, February 21, 2011). Similar to his music discourse, he experiences the immediate feedback from running the software he writes *(with software, you write whatever it is, you know, 100 lines of code, and you run it and there it is, you see it. So there's this, there's this wonderful direct feedback that's very gratifying)* (Ethan, personal communication, February 21, 2011).

Unlike Meg, who is personal and agentive when describing the contexts that bring her to that abstract state, Ethan positions himself as a distant expert. This distance is demonstrated with his frequent and exclusive use of the pronoun *you* when describing the concrete actions that lead him to the abstract state of being in the zone in the music context *(you are in a sea of people… you are all moving… you're responding… you're working together)*, and in the computer-science context *(if you're coding… you're in the zone… you write, you run it, you see it, there's this wonderful direct feedback)* (Ethan, personal communication, February 21, 2011). It is possible that Ethan's exclusive use of *"you"* is designed to further the interviewer's involvement in understanding this complex psychological phenomenon. Alternatively, it may be used to

[118] Out-of body experiences (OBEs) are personal experiences during which people feel as if they are perceiving the physical world from a location outside of their physical bodies.

maintain linguistic uniformity, by introducing the second person pronoun throughout all concrete actions, to match the more abstract reference of "you're in the zone."

Reaching the mental state of being in the zone and the feelings it entails, especially the feeling of immediate feedback from an activity, provides Ethan with the feeling of gratification *(there's this wonderful direct feedback that's very gratifying)* (Ethan, personal communication, February 21, 2011). This immediate feedback also provides Ethan with empowerment *(the whole thing about feedback and empowerment)*, a sense of personal control of an activity, and yet another component of flow (Csíkszentmihályi, 1990) (Ethan, personal communication, February 21, 2011).

Ethan's experiences of gratification and of empowerment can be traced back to three disciplines in his life. As a computer scientist, he feels gratified when receiving immediate feedback from running code that he writes *(you write… 100 lines of code, and you run it and there it is, you see it. So there's this, there's this wonderful direct feedback that's very gratifying)* (Ethan, personal communication, February 21, 2011). He also feels empowered from code writing, especially when interacting with simulation programs he writes for measuring and improving systems' performance *(empowerment, it's empowerment, that you can build a model, a predictive model… and you can then, ask all these 'what if' questions… very empowering)* (Ethan, personal communication, February 21, 2011). Prior to being a computer scientist, Ethan experienced gratification and a sense of empowerment throughout his early involvement in orchestral performances *(when I started playing in bands and orchestras at an early age... there're two things that I got out of it, one, is um, this instant gratification. You're playing and ah, you're experiencing at the moment, like a lot of art, it's one of those things where the, the application of producing sound, or whatever you're producing as an artist comes back to you* *instantly, and if you're doing it right, and so forth, it's gratifying. And the second one is empowerment, in a certain kind of way, you are producing something that for me was a very empowering)* (Ethan, personal communication, February 21, 2011). Finally, his sense of empowerment possibly originated in his childhood at the young age of eight, with his discovery of rapid mathematical calculations through the slide rule *(I had a real interest in, in mathematics… I found it empowering in a certain kind of way… the slide rule, I found it very empowering that you could actually do the calculations very quickly… so I think to me, looking back at it, it was very empowering, mathematics)* (Ethan, personal communication, February 21, 2011).

Throughout the entire three discourses on computer science, music, and mathematics, Ethan alternates between his positioning as a distant observer of his empowerment experience and his positioning as the agent. This change in positioning is achieved through his alternating use of the pronouns *"you"* and *"I,"* with the computer-science discourse populated only with second person pronouns *"you,"* the music discourse equally mixed with both pronouns, and the mathematics discourse populated mostly with *"I."* I hypothesize that these shifts may represent changes in the degree of intimacy Ethan feels toward his empowerment in a particular discipline. As such, it is possible that Ethan is most intimate with the empowering effects in the discipline of mathematics, either because of the concreteness of playing with the slide rule, or perhaps because it was the original discipline in which he experienced empowerment. As such, not only that music-making and computer-science work can create the mental state of flow for Ethan, but they can also instill in him feelings of gratification and empowerment through reaching this state.

Apart from the routine practice of technical passages where he can afford thinking about other things, Ernie, a clarinetist and computer scientist, is in complete focus and in the zone while working on the expressive power of music *(like thinking musically… and trying to do something with the music)* (Ernie, personal communication, February 16, 2011). Reaching the mental state of being in the zone induces the best music playing in Ernie *(the best kind of playing is when you are ah, that's all you're thinking about… if I'm performing, I should be completely in the zone and that's all I'm thinking about)* (Ernie, personal communication, February 16, 2011). Despite the centrality of music to his Harmonix business, Ernie cannot be distracted during work by listening to music like other people *(if the music is playing, I have to listen to the music and I'm not concentrating on what I'm doing)* (Ernie, personal communication, February 16, 2011). His current work, which involves looking at financial models, management of people, brainstorming and evaluation of new ideas to work on, necessitates total concentration *(mostly when I'm focused on whatever it is what I'm doing… right when I'm in the moment, music is not really there, in my head)* (Ernie, personal communication, February 16, 2011). Compared with Meg and Ethan, Ernie is more personal when describing his reaching the state of being in the zone *(if I'm performing, I should be completely in the zone),* with the reservation that he presents it as his expected logical consequence of performing, rather than stating a fact. When describing his being in the zone at work *(right when I'm in the moment, music is not really there, in my head),* with "in the moment" buzzword for being in the zone, Ernie is completely personal (Ernie, personal communication, February 16, 2011). This personal style possibly reflects Ernie's deeper intimacy and authenticity with the state of being in the zone, which might be associated with his continuously growing challenges at work and at his music engagements.

Miro, a pianist and computer scientist, acknowledges the extended period of practice involved in getting to the point where one can experience flow induced from both music and programming. He believes that with their intense practice, professional music performers reach the state of flow *(professional pianists practice about eight hours a day and they've got a certain, ah, flow going there)* (Miro, personal communication, March 17, 2011). In programming, as well, startup time is lengthy and requires mental organization *(programmers get into flow, writers get into flow… it can take a long time for a writer or programmer to get started)* (Miro, personal communication, March 17, 2011). Once reaching the state of flow, if not interrupted, programmers become productive *(where you get to a certain level where you're just kind of cruising, you're productive)* (Miro, personal communication, March 17, 2011). Although Miro does not specifically acknowledge his own experience of flow, he implies it indirectly through his use of the linguistic inclusion device of referring to generic groups *(*[e.g.], *professional pianists… they've got a certain, ah, flow going there; programmers get into flow)*, which he is a member of (Miro, personal communication, March 17, 2011). Miro also believes that early start of piano practice facilitates subsequent concentration later in life, and should be experienced by all children *(it's the opposite of instant gratification… it's inner up driven… practicing does give you the discipline of sitting and concentrating on something for you know, and hour or two, because in working a lot of, a lot of professions like programming, you basically have to um, maintain concentration on something)* (Miro, personal communication, March 17, 2011).

As with Meg, Ethan, and Ernie, Miro's musical life began early in his childhood, with computer science becoming a later endeavor. As such, it is sensible that his early piano practice helped Miro maintain extended periods of concentration in his later software design and programming work, and reach the state of flow.

In one of his studies on flow and creativity, Csíkszentmihályi (1990) demonstrated that flow experienced at work, directly contributes to happiness and to work satisfaction in the sense of being active, creative, focused, and motivated. In addition to work-induced flow, he showed that leisure-induced flow also contributes to work, as his study participants experienced several negative consequences after being asked to refrain from engaging in their favorite leisure activities. Csíkszentmihályi discusses music-making as a leisure activity that induces flow, and thus asserts its indirect contribution to productivity at work (Csíkszentmihályi, 1990, p.108).

Ethan, Miro, Ernie, Meg, and Delia, during their rich musical past, express their happiness and satisfaction from music-making. However, they all acknowledge that their happiness and satisfaction are largely due to having music-making integrated with their parallel work pursuits, rather than a standalone activity. This aligns with observations made by leisure researchers Haworth (2004) and Zuzanek (2004) regarding the possibility of increased happiness and reduced stress, respectively, as a result of engaging in leisure in addition to work. Ethan is happy with his music-making *(music makes me very happy… it can be a deeply spiritual experience),* and acknowledges its contribution in facilitating his analytical problem solving *(it's very important to me in many ways… it helps me pull things from the other side* (Ethan, personal communication, February 21, 2011)*).* Miro's happiness with music is one of his needs and loves *(I kind of need to have music in my life. I need to have computers. I love the process of programming, that's mental exercise… I've got to have pets. I've got to have a* cat or a *dog or something. And, I think I'm happier having all three*) (Miro, personal communication, March 17, 2011). Ernie is quite happy too, as music adds a dimension different from his work experience and therefore makes his life experience more interesting and unique *(overall I think I'm pretty happy, you know, and um also I have these two different experiences that most people don't have or… I think having the two just makes the world much more interesting)* (Ernie, personal communication, February 16, 2011). When Meg expresses her happiness from her chamber music playing *(I was very happy to play with Robert Koff),* she is immediately reminded of how a particular chamber music performance energized and delighted her at work *(we went to Hobart and William Smith Colleges... it was to celebrate J.S. Bach's ah birthday… it was just a really fantastic like experience, where I felt, you know, completely transported… I came back to the job, and this was like an exhausting start up job, I mean I worked a billion hours a week, but I came back to the job and I felt more rested, it was as if I'd had a three week vacation at the beach)* (Meg, personal communication, April 2, 2011). Finally, Delia also acknowledges her excitement from the integration of music with her work *(I feel good when I do this mixture, not only work, work, work, but there is something that I'm doing for myself)* (Delia, personal communication, May 5, 2011).

Evident from the above analysis, musical computer-scientists have experienced flow in both their music and computer-science activities, but are not able to articulate the primary discipline in which flow originated. Since these individuals began their serious music-making early in their lives, it is feasible that flow was first experienced in the music discipline. As their happiness from music-making is partially derived from its link to their work pursuits (as discussed in the previous paragraph), it is possible that abilities for achieving flow in music-making, such as the ability to concentrate while playing, have transferred to the target domain of computer science, as the ability to concentrate while programming. While individuals may not be aware of this transfer process, researchers (Gentner, 1983; Holyoak and Thagard, 1989) have speculated that analogical reasoning and purpose[119] play an important role. Moreover, such diverse experiences of flow likely nurture an abstraction and therefore a further transference of various aspects of flow (Gick and Holyoak, 1983). This might make musical computer-scientists more capable of

[119] Multiconstraint theory of similarity, analogical reasoning, and purpose is a theory of analogical thinking in which three constraints of similarity, structure, and purpose jointly encourage coherence in analogical thinking.

getting into flow in new situations (e.g., when practicing a new instrument) or disciplines. Using concepts from dynamic skill theory (Fischer and Bidell, 2006), the more a skill has been reorganized through multiple differentiations and integrations along its developmental pathway (i.e., it has been practiced in various ways), the more successful its transfer is likely to be to the target skill.

2. Engineering/Scientific Mindset

Through their reflections on childhood interests, school projects, work assignments, and music endeavors, musical computer-scientists implied using skills typically associated with an engineering way of thinking, in both music and computer-science activities. These skills include an analytical way of thinking, and visual processing of information.

a. Analytical Mind

Study participants have demonstrated an analytical way of thinking in both their music discipline and work. Their analytical mind has emerged during their early childhood occupation with construction sets and mechanical objects, and was further expressed through their pattern-oriented and structural-thinking methodologies in both disciplines.

i. Emergence of Analytical Skills: Building with Construction Sets and Mechanical Objects

Ernie's analytical mind manifested in his childhood with his passion for building with Lego blocks and mechanical Legos using motors *(I always loved building things, that's the one kind of thing I can remember all the time… I had, I had Legos and I would just, I would be playing with them a lot… always building things)* (Ernie, personal communication, February 16, 2011). As evident from Ernie's self-reflexivity in the previous narrative segment, Ernie constructs his identity as a passionately productive and creative self. With his use of the temporal marker "always," Ernie also introduces continuity and constancy to these positive qualities, positioning himself as a creative and productive person throughout his life. Ernie's reflexive evaluation of his self as a creative builder, is substantiated with the assertions made by Root-Bernstein, R. and M. (2001), that playing with these classical construction toys in which a limited number of structural units provides unlimited opportunities for imagination, helps kids become designers and inventors. Indeed, Lego blocks signify a unifying thread throughout Ernie's creative life, as he later on created and incorporated a Lego-based, piano-roll scrolling motor in the innovative music-recognition system he developed with his mentor at the MIT Media Lab (discussed in the next section).

Ernie is also self-reflexive about his preference of Lego blocks that came along with accompanying instructions over the free-form ones *(I kind of liked both, I actually really did like following the instructions and… going through the pictures and the steps and going along the way and eventually getting to the thing as it was supposed to be)* (Ernie, personal communication, February 16, 2011).

Ernie's affinity for building is also reflected in his frequent use of the "build" terminology in his narrative. It is reflected in representative phrases in his computer science discourse *(building a website; I'm drawn to computer science and building and engineering; you build a computer with um, like connecting chips and wires together; I ended up building a system that could listen to, to some music; building software; build a company)* as well as in his music discourse *(you use a metronome so you start off slow and kind of build up; I start really slow and I kind of build up)* (Ernie, personal communication, February 16, 2011).

Like Ernie, Meg also enjoyed building with construction sets in her childhood *(but I spent a lot of playing, building buildings with Lincoln logs),* although was held off by her parents from certain toys *(I was really ticked off that my parents wouldn't get me an Erector set, because I wasn't a boy or something)* (Meg, personal communication, April 2, 2011). Meg's blame of her parents for living through the consequences of their gender-bias is demonstrated in her use of the linguistic intensifier *"really,"* and her passive voice, which emphasizes her anger and resentment *(I was really ticked off)* (Meg, personal communication, April 2, 2011).

The use of passive versus active voice has been identified by Labov (1997) as one of several linguistic devices used in the assignment of blame and praise in oral narratives of personal experience. Additional such devices include mood, causality, evaluative lexicon, insertion of pseudo-events, and the wholesale omission of events. With the creativity encouraged by playing with construction sets, it is possible that Meg's resentment is actually targeted at her parents for impeding on her creativity, as they attributed creativity only to males. Balancing her blame, Meg praises her father for inspiring her love of building and modeling through jointly building airplane models at her young age of three or four years *(we built a lot of um, you know, WWII era airplane models and made mobiles out of them)* (Meg, personal communication, April 2, 2011). She is also appreciative of his intelligent mentoring while fixing cars, encouraging observation and hands-on experience *(he was always doing something fascinating, taking a car apart… and all the neighborhood kids, most particularly the boys, would congregate… sort of running commentary as he'd be doing things, letting them do things, telling them about what he was doing… a real popular guy… so we took apart, you know, the engine in a VW bug a bunch of times)* (Meg, personal communication, April 2, 2011). Meg's assignment of agency to her father's productive actions, her attributing permanence to his agency with the temporal marker *"always,"* her detailed description of his mentoring scenario, along with her praising lexicon *(fascinating, a popular guy)*, all serve to strengthen her praise (Meg, personal communication, April 2, 2011).

In her narrative, Meg, like Ernie, frequently uses the *"build"* terminology. She uses it in reference to her computer-science activities *(I really tried to build systems that are adaptive; on this presentation I hit on two things. First thing was specification. So I said, "build me an arc of gopher wood... it has to be 100 cubits," I probably would have just tried to build my own business),* and her model building activities *(I liked model building*; *I spent a lot of playing, building buildings with Lincoln logs*; *I'm really sort of astounded that I didn't become a building architect*) (Meg, personal communication, April 2, 2011).

Ethan, like Ernie and Meg, also developed a passion for building and modeling, inspired by his older, bomber-pilot brother, who also inspired him to become an amateur pilot. Together they built radio-controlled airplanes, rebuilt a broken pump organ, and fixed old TV sets *(my brother and I did things together… we would build these airplanes ah, like a six foot wing span, huge airplanes… you'd get the plans and buy the materials and make the frame, the skins, and then you can buy these engines and put it in, mechanical relays)* (Ethan, personal communication, February 21, 2011). With his recurring use of the second person pronoun *"you"* in this narrative segment, Ethan repositions himself from a young, naïve builder to an expert in the field who elaborates on his actions, possibly assuming the interviewer is not verse in the mechanical domain. Ethan, too, uses the "build terminology" in his computer-science discourse *(build a software product; building models, performance models; build mathematic analytical models; takes the planning down to, I call it the build level),* as well as the more conventional engineering building discourse *(build a bridge; building very large houses)* (Ethan, personal communication, February 21, 2011).

Like Meg and Ethan, Miro was also initially inspired by a family member (his father) to engage in electronics things *(he knew about repairing things and electricity. So I could read circuit diagrams, because he taught me,* and *fix radios and fix TVs)* (Miro, personal communication, March 17, 2011). His mechanical interests, though, evolved around music artifacts. Listening to music, Miro became fascinated with the mechanics of the record changer *(I'd watched it, there were record changers in those days for 78 RPM records… that was fascinating to watch)* (Miro, personal communication, March 17, 2011). As the organ was one of his favorite instruments *(I've always been interested and fascinated by the organ),* Miro took up the task of building an electronic organ from a kit of precut wood parts and circuit boards *(I thought "this would be such a wonderful thing to have"… over the course of about four to five months I put the whole thing together… it's the type of thing, like some type of cars, to keep it working you have to do a lot of tinkering with it)* (Miro, personal communication, March 17, 2011).

With the tight link between Miro's electronic and mechanical inclinations and his passion for music, it is feasible that his other scientific, mathematical, and computer-science inclinations were also tied with his passion to music. Miro alludes to this tie through his even itemization of his passions in a list *(I loved music all along and I've loved mechanical things, and electronic things, and math, and science, and computers)* (Miro, personal communication, March 17, 2011). This tie may have stemmed from his childhood visits with his neighbor, an electronics engineer and music lover. At his basement, Miro would simultaneously listen to his huge classical record collection, read *Scientific American* magazines and solve their mathematical puzzles, and watch his neighbor build things *(I wanted to read the magazines and I wanted to listen to the music and so I did them both at once… he had a shop in the basement with a metal lathe so he could make all the metal parts for the steam engine. So he was like always putting things together, always trying things, always designing things)* (Miro, personal communication, March 17, 2011).

Both pilot study participants, David and Martin, also demonstrated a passion for modeling cars and building with constructions sets, respectively (discussed in the Pilot Study section of the Methodology chapter), predicting the potential saliency of the building and modeling inclinations theme in the real study.

Altogether, with the emergence of their mechanical activities, musical computer-scientists have begun to experience the following aspects of creativity, at the minimum: they engaged in playing and exploration via observational and hands-on skills, practiced modeling, and began synthesizing their mechanical world with music and mathematics, a significant subset of the thinking tools that Root-Bernstein, R. and Root Bernstein, M. (1999) consider belonging to the world's most creative people.

ii. Expression of an Analytical Mind: Pattern-Oriented and Structural Thinking

With his analytical mindset and experience with music from the classical and romantic periods that lends itself to patterns, Ernie is capable of identifying patterns where patterns are not as obvious, like in contemporary music, helping him to learn that music better and faster *(if you just start playing it initially, you're like I don't know where this is going, is this atonal or what? But then you look at it more closely and then you realize like oh I see, oh it is, it is, it has tonalities, it's just changing it every beat… it has this scale, it'll play four notes of a scale in C major, and the next is F sharp major and C major and F sharp major, and it's just, oh okay, I* *see that's what's going on… that kind of analytical uh, that thing helped… helps you understand what is going on in the music and then helps you learn it better)* (Ernie, personal communication, February 16, 2011). To identify patterns, Ernie most likely uses his eyesight, as indicated through his use of the verbs *"look"* and *"see."* Used colloquially, these verbs could also yield the more vague meaning of observing, implying, for example, aural pattern-recognition. This interpretation is less likely, as aural pattern recognition can be accomplished through a musical piece that has reached some level of competency, a state which doesn't necessitate that Ernie resort to patterns.

The presence of patterns in musical compositions, like the ones Ernie alludes to, has been discussed by researchers who attempt to relate the two disciplines of mathematics and music (Graves, 1981; Rothstein, 1995; Fauvel, Flood and Wilson, 2003; Chang, 2004). They discuss various transformational patterns along the various dimensions of pitch, rhythm, contour, and timbre. For example, a simple transformation along the pitch dimension is the translation of a sequence of notes across different scales while preserving the melodic line of the original sequence (i.e., transposition). The activity of pattern recognition is perceived as one of the skills used by creative people, as it is essential in discoveries when observations do not fit into expected patterns or when one perceives new connections between seemingly unrelated things (Root-Bernstein, R. and M., 2001). Believed to be shared by scientists, mathematicians, and musicians (Boettcher, Hahn and Shaw, 1994; Root-Bernstein, 2001; Chang, 2004), it is feasible that musical computer-scientists are highly creative as they habitually practice this pattern-recognition skill in multiple contexts.

Stan, a timpanist and a computer scientist, uses patterns, but in a different way than Ernie–he thinks in gestalt mode *(sort of overall, big pattern)* to fully comprehend a situation (Stan, personal communication, February 17, 2011). In this mode he steps back to see the whole picture after looking at the details, to see how the details fit together into the big picture *(I read through details and then try to step back and visualize what's going on… and then I don't feel I can fully understand it until I fully pull back, and picture it as a whole)* (Stan, personal communication, February 17, 2011).

Stan uses the gestalt way of thinking in his three worlds of music, math/computer-science, and his social world, but is not aware of the discipline in which he practiced this thinking first. In music, visualizing the big picture enabled Stan to overcome the rhythmic difficulties of a Bartok sonata for two pianos and two percussions, while using detailed counting of rhythmic beats *(I looked at the detail enough, but I could only go so far with the detail, and just had to step back, and see how it fit in with the rest)* (Stan, personal communication, February 17, 2011). By listening to the pianist's part, Stan could visualize his own rhythmic part blend in, thus eliminating the need for detailed rhythmic counting *(I just could tell how what I was supposed to be doing blended with that… I could stop counting at that point, whereas, before that I was counting like mad to get the exact rhythm… it was quite remarkable, because it made, what had been the hardest part of the piece for me, the easiest one, because I could just sense what was going on, what it was supposed to sound like)* (Stan, personal communication, February 17, 2011).

When learning technical material in mathematics, like understanding complicated theorem proofs, Stan also relies on seeing the big picture after following the individual steps of the proof *(because you can sort of study all the details, until you step back–at least for me–until I step back and try to picture it… it's like trying to grasp the whole thing at once, is when I feel comfortable with it)* (Stan, personal communication, February 17, 2011). Demonstrating a proof step by step, like what his professor did initially, was sufficient for Stan only for reproducing but not for fully understanding the proof. But with the new perspective provided by the same professor, looking at the big picture of the proof, Stan eventually got the essence of the theorem *(it was clear why this theorem was true)* (Stan, personal communication, February 17, 2011).

Gestalt thinking has accompanied Stan also in social situations both as a kid and as a young adult, especially during individual interactions when he needed to step back and observe a situation *(kinda see what's going on here)* (Stan, personal communication, February 17, 2011).

The jigsaw puzzle is a powerful metaphor used by scientists to describe their gestalt pattern-recognition activity, especially with respect to conceptualizing during data analysis. Scientists engage in assembling pieces of a jigsaw puzzle or even pieces from different puzzles mixed together with no guide as to which pieces go together, in order to make sense of the big picture. As reported in Root-Bernstein, R. and Root-Bernstein, M., (1999) Nobel laureate and embryologist, Christiane Nusslein-Volhard, says that “the most important thing is not one particular piece, but finding enough pieces and enough connections between them to recognize the whole picture” (p. 104-105). Nobel laureate and physicist, Chen Ning Yang says that “you don’t constantly attack one problem. If you have a lot of small linkages, you try to make them fit and then once in a while you find five pieces together. The joy is indescribable” (Root-Bernstein, R. and Root-Bernstein, M., 1999, p. 105).

Ethan also learns and thinks in a gestalt manner in both disciplines of music and computer science. Moreover, he believes his gestalt way of learning evolved from his early music-making engagement where it helped him in learning and memorizing music *(you have a general gestalt, there's this piece, there's three movements, the first one’s got this theme in it and then it starts out like this, you just learn the general and you learn how to move down* *to the specifics… for me, it's to memorize certain road marks ah–landmarks–and then the stuff in between it… that's something I learned at an early age)* (Ethan, personal communication, February 21, 2011).

Ethan describes his gestalt thinking when managing software development projects through an analogy to his orchestral experience *(we rehearse doing the project, multiple times, and I call that the dress rehearsal)* (Ethan, personal communication, February 21, 2011). As with music, he typically starts from the big picture and then moves in a top-down fashion to the details *(in managing software, I learned over the years as an executive, you plan extensively, there's nothing worse in a software project where everyone goes off and starts doing their own thing…. I'm the type that takes the planning down to, I call it the build level, where everyone knows what they're going to do, and the way I plan it, is I bring a whole team in… we start going over what we're going to do)* (Ethan, personal communication, February 21, 2011). Combining the implications from Ethan's structural analogy (the orchestra = programming team; the conductor = Ethan, the project leader) with his acknowledgment that music is his source domain for gestalt thinking, it is likely that Ethan's gestalt thinking did transfer from his music-making to his computer-science world (Gentner, 1983; Holyoak and Thagard, 1989).

In addition to his gestalt-oriented thinking, Ethan reveals nuances and structural relationships by reading music scores like one reads books *(I take a score to bed)* (Ethan, personal communication, February 21, 2011). These discovered relationships, which he cannot or does not perceive while listening to the music, facilitate his music performance *(there's a certain joy in doing that because you can pick over the music, ah, you can go back and forth on a couple of measures and really pick through it and really um, get a wonderful understanding of what's going on there).* Using this scanning method when practicing the cello sonata by Russian composer, Myaskovsky (1881-1950), Ethan discovered how alternating harmonies between the piano and the cello cradle the melody, and identified hidden rhythmic phenomena *(sometimes it's polyrhythmic, the piano is doing one* thing *and the cello is doing another thing, and again its magic)* (Ethan, personal communication, February 21, 2011).

Overall, Ethan thinks and learns in a structured fashion *(I tend to structure things*), which was likely first practiced through his music-making and then transferred to his planning and organizational thinking at work (Ethan, personal communication, February 21, 2011). It is no surprise, therefore, that Ethan identifies with the life of British astronomer and musician, Frederick William Herschel (1738-1822), one of his favorite historical figures, who was inspired by music when reading star patterns and discovering planets *(the way he understood the constellational maps, the star maps, he could easily find things, he saw them as musical, as pieces of music)* (Ethan, personal communication, February 21, 2011).

Meg, too, sees the importance of perceiving and presenting the big picture. When delivering presentations on her genomic-system architecture to her audience of molecular biologists, she insists on presenting the big picture. This way she ensures that all prospective system users have a uniform and full understanding of the system, rather than just their own micro-world of details *(if everyone isn't on the same page and doesn't… understand things or have consensus on what the understanding is of a big system, you're sunk… the mind of the molecular biologist, they're a very bottom up kind of thinkers… they're very inductive. So they don't want to hear about, kind of grand plans for software, they don't think about things top down)* (Meg, personal communication, April 2, 2011).

Sol, a pianist and computer scientist, is analytical with respect to his everyday life and his work *(I always want to know how things work… I think I'm naturally a pretty inquisitive person*)

(Sol, personal communication, February 28, 2011). When he recently had solar panels installed at his home, he did not settle for them just to be installed but rather got involved in understanding their design and how they worked.

With music, Sol typically turns his analytical mode on in two occasions: while carefully listening to music and when programming music systems. His analytical listening is an activity he does not typically engage in and considers a completely different discipline than playing music *(I think of music as a sort of a long string of stuff… like speech, to some extent, and so I hear it that way, I have to work, I have to sort of turn off… the appreciative part of the listener, and turn myself into an analytic mode)* (Sol, personal communication, February 28, 2011). It helped him identify themes in a quartet piece he knows quite well but never paid close attention to *(I never sort of stood back from, and watched exactly how the composer had put it together, you know, and how they appeared and reappeared in different guise, and I did that in that particular performance)* (Sol, personal communication, February 28, 2011).

Viewing music analytically became inevitable when Sol began programming his music system, which helped composers capture their ideas by first playing them on the piano *(then it suddenly became necessary to look at the thing… look at music structured, especially piano music, analytically)* (Sol, personal communication, February 28, 2011). Programming the machine to reliably propose music scores that were played on the keyboard synthesizer, required pattern-oriented structural analysis of the played harmonies and melodies *(because the piano is an instrument that can play many notes at the same time… emulating an orchestra or a, some group of musicians… piano music really consists of multiple parts very often, and recognizing that structure was very important)* (Sol, personal communication, February 28, 2011).

Although not explicitly acknowledging his structural thinking, Miro, simultaneously listens to music and reads its score, which enables him to perceive the underlying structure of the played music *(I'd sit at home and listen to Beethoven's symphonies or Stravinsky or opera following the score… it was really fun to do, you were uh getting the music two ways, you were getting the music by listening to it and you were reading the score kind of seeing how it's done)* (Miro, personal communication, March 17, 2011).

Overall, musical computer-scientists employ pattern-oriented structural thinking when playing music as well as when working. In music, this thinking helps their practice and listening abilities, and improves their memorization and performance (Ernie, Sol, Miro, and Ethan). At work, this thinking facilitates their problem-solving skills (Stan, Sol) and helps them better manage their projects (Meg and Ethan).

iii. Expression of an Analytical Mind: Divide-and-Conquer Thinking

In addition to pattern-oriented thinking, musical computer-scientists would sometimes resort to another analytical problem-solving methodology, that of divide-and-conquer.

When Ernie's pattern-oriented thinking cannot yield any obvious patterns while practicing the technical aspects of his music, he will try to break the musical piece into smaller pieces, practicing each small piece and then putting the small pieces together *(what do engineers do? they break it down into smaller problems)* (Ernie, personal communication, February 16, 2011). This divide-and-conquer process helped Ernie to promptly prepare a complex contemporary piece with a dense page of random triplets for a performance. Not being able to identify obvious patterns, Ernie broke the triplets down to smaller blocks, working on one block at a time *(it seems random, I don't see any patterns… there's no particular scale… what do engineers do? they break it down into smaller problems)* (Ernie, personal communication, February 16, 2011).

Working on one block, starting slow and then building up on tempo, Ernie could calculate his total practice time leading to the performance date *(I'm just going to break things down into, into blocks, and then calculating whether, you know how it's going to work)* (Ernie, personal communication, February 16, 2011).

Ernie is certain that his analytical predisposition and acquired analytical skills affected his perception of music practice throughout his life *(my personality and the fact that I'm very analytical and the fact that I'm drawn to computer science and building and engineering, definitely uh, uh… has an influence over how I think about music and how I think about practicing)* (Ernie, personal communication, February 16, 2011). Ernie's reference to thinking about music *(how I think about music)* and his emphasis on practice *(how I think about practicing)* amplifies his perception of the importance of the technical dimension in understanding and learning in music *(you spend a lot of time on the technical stuff… that kind of analytical… helps you understand what is going on in the music and then helps you learn it better)* (Ernie, personal communication, February 16, 2011). Perceiving the technical dimension as necessary but not sufficient for enjoying music, Ernie cherishes the emotional and expressive dimensions *(there's the technical piece and there's the emotional piece… you have to have the plumbing and all the stuff to get, you know, and once that's there then you can start thinking about expression, and okay what am I trying to convey in this piece…emotionally it's very satisfying to be playing music)* (Ernie, personal communication, February 16, 2011).

With music being a tangible scale for measuring progress, it has informed Ernie's thinking at his computer-science work, especially in making and evaluating his more vaguely defined progress at work *(with learning a piece of music you can really see how you make progress… I'm seeing myself, like get better, you know, physically get better at doing something, you know, in a* *relatively short period of time um, when you're practicing… what happens with music really kind of gives you the confidence that yes, people are capable of improving in very, sort of material concrete ways if they work on something you know and that's kind of a refreshing thing, you know, to know that.)* (Ernie, personal communication, February 16, 2011). Using music as his scale for measuring progress has helped Ernie improve at his concrete programming tasks as well as at his more recent high-level management tasks at work *(I've clearly gotten better at becoming a manager… people here, who I've hired, have helped me become a better computer scientist, you know, better programmer,* seeing *how this stuff works, so you know, I definitely gained, you know, confidence there and being able to do things… so if I look at points in time, like now versus five years ago, ah ok I think I'm better now than I was back then)* (Ernie, personal communication, February 16, 2011).

Given Ernie's fascination with configuring structural objects at the early age of five along with his admitting to an analytical personality and predisposition *(my personality and the fact that I'm very analytical…),* it is possible that Ernie has been endowed with an innate analytical ability, similar to what Gardner (1998) calls mathematical-logical intelligence (Ernie, personal communication, February 16, 2011). People with this type of intelligence are good at abstract reasoning, recognizing patterns, and at logically analyzing problems, like Ernie is. Another possibility is that Ernie has an analytical predisposition, that made him focus his attention initially on relevant environmental inputs like Lego blocks, and that later progressively modularized through his experiences to a more comprehensive analytical, mathematical, and engineering skills (Karmiloff-Smith, 1994). This latter hypothesis is in line with the sophisticated, cognitive development theory of "genes with environments," in which environmental factors affect gene expression (Ridley, 2003; Grigorenko, 2007; Ehrlich and

Feldman, 2007; Harris, 1998), and genes affect the environments experienced and sought by individuals (Scarr and McCartney, 1983).This is contrasted by the more naïve view of "genes versus environment" in which cognitive development is due to either the individual's genes or the individual's experience.

Overall, it is likely that Ernie's innate or predisposed analytical abilities were first illustrated with his passion for Lego building and in his success in mathematics *(I ended up in the most advanced math class)* (Ernie, personal communication, February 16, 2011). Subsequently, they have most likely transferred to his music world and later on to his engineering and computer-science worlds, where they are feeding on each other: his engineering mindset helps improve his music technique, and music helps inform his progress at work.

Meg, like Ernie, has applied a divide-and-conquer approach to practicing her music pieces especially when practicing her rhythm as a youngster. To better understand complex rhythmic patterns, she used her mathematical skills to break them down into smaller units and then put them back together *(it wasn't until I got to the conservatory, that you know, I understood how to… really breakdown very complex rhythmic patterns into essential twos and threes and put them back together… I think there was something that went on there with understanding of math and so forth that made it possible for me to realize, you know, how to correct that problem in my playing)* (Meg, personal communication, April 2, 2011).

Meg has also been using similar divide-and-conquer methods at her work when working on her huge, complex genomic systems *(to a great degree that's kind of what you do with computer science or when you're doing engineering, right. You have a big problem, well one of my friends at work… she says, "we have to take this huge big elephant problem and turn it into elephant* *burgers."…It makes small chunks and that's what really makes it something that you can attack a big problem and be successful)* (Meg, personal communication, April 2, 2011).

Overall, it is likely that Meg, too, has innate analytical abilities or a predisposition toward these abilities. Like Ernie, these were first illustrated with her passion for building with constructions sets, mechanics and modeling, and in her early success in school geometry. Subsequently, these abilities have most likely transferred to her music world and later on to her engineering and computer-science worlds, where her engineering mindset helps her to overcome rhythmic problems and successfully organize her project presentations at work.

b. Spatial/Visual Ability

In this section, I explore the occurrence, use, and meaning of visual thinking in the lives of study participants, both in music and computer science.

According to Arenheim's (1986) *A Plea for Visual Thinking*, analytical ability (processing information) has been incorrectly considered separate from and superior to visual ability (perceiving information). Following Arenheim's claim that this separation and superiority does not align with the way our minds work, recent studies have shown the importance of visual thinking. It has been shown that visual ability is important for certain technical occupations like engineering, for understanding basic chemistry and structural chemistry (Barke, 1993), and that it is the most significant predictor of people's ability and success in interacting with computers (Norman, 1994). Moreover, through biographical accounts, Root Bernstein (1999) shows that visual thinking has been a central thinking tool in the discovery and development of technological advances that have had a long-term impact on society.

In addition to her analytical qualities, Meg is endowed with visual skills, as evident from the three main contexts in which she practiced them, including map drawing, geometry, and navigation. First, in her youth, Meg was consumed by drawing maps *(I was a very good artist, was obsessively interested in maps, and so I would draw maps, free hand for hours, not trace them but just sort of draw them free hand)* (Meg, personal communication, April 2, 2011). Second, she excelled in her geometry classes during junior high school *(I was the best student at solid geometry)* (Meg, personal communication, April 2, 2011). Third, Meg directly asserts her possession of visual abilities, which becomes obvious when she expresses driving directions using cardinals like “head north” rather than landmarks *(I had very good spatial um you know, understanding for a woman)* (Meg, personal communication, April 2, 2011).

With her visual skills and passion for model building, Meg questions her not pursuing a career in architecture *(I'm really sort of astounded that I didn’t become a building architect, because I really love, until this day, I love architecture)* (Meg, personal communication, April 2, 2011). Although not a building architect, Meg has specialized in computer-systems architecture *(I definitely had ability at doing, you know, huge system designs… I led the team, and architected a lot of the software, I’ve started out kind of like an architect, designer position… we did this huge thing and I was the chief architect of that)* (Meg, personal communication, April 2, 2011).

Meg is aware of the contribution of her visual skills to the understanding of both music and computer science *(there’s no question that there’s a lot of relevance between spatial ability, mathematics and music… absolutely they go together).* For example, she comprehended the complex rhythm of African drumming and its additive characteristic only through an analogy to the New England Farmhouse, an additive kind of a structure *(you can add another room on without having to tear the whole structure down…you walk through the third bedroom to get to the fourth bedroom… each room that you’re presently in is very comfortable and it's extremely* *well understood what the function of that room is)* (Meg, personal communication, April 2, 2011).

Meg's visual image of the adaptive architecture of the New England Farmhouse has also informed her flexible and adaptive design of software systems she developed *(the analogy was, that if you built software like a New England farm house, which essentially was an additive kind of structure, like additive African rhythm, you end up you know, kind of gracefully adding on…more things that you need)* (Meg, personal communication, April 2, 2011). Analogizing to that visual image, Meg was able to successfully design flexible, general-purpose genomics software systems, as opposed to rigid ones. This system flexibility was particularly valuable for accommodating scientists who were not usually able to specify their exact system requirements *(this worked great for me as a concept when I was… doing systems in genomics and genetic stuff, because the scientists would never know what they wanted. So it was impossible to get requirements up front)* (Meg, personal communication, April 2, 2011).

Meg makes references to both her probable innate abilities of visual thinking *(I was obviously exposed to a lot of testosterone in the womb, because I had very good spatial um you know, understanding for a woman)*, and to environmental effects on her visual abilities *(we built a lot of airplanes… I sniffed too much glue as a child; I did a lot of car models… it's spatial, right)* (Meg, personal communication, April 2, 2011).

Overall, given Meg's admissions, it is likely that Meg has an innate visual ability as depicted in Gardner's (1998) spatial/visual intelligence, or that her visual skills budded from her early predisposition to such skills, and further redeveloped through their practice in various environments (Karmiloff-Smith, 1994), like map drawing, car modeling, geometry, and navigation. Regardless of their origin, these visual abilities likely also transferred to her music and software design worlds.

Spatial/visual abilities, like the ones described by Meg, have been found to be highly correlated with scientific success (Root-Bernstein R. S., Bernstein, M., and Garnier, H., 1995), and contributory to creativity (Root-Bernstein, R. and Root-Bernstein, M., 1999). Shared also by musicians who often practice these skills simultaneously with aural and kinesthetic skills, makes polymaths like musical computer-scientists highly creative (Root-Bernstein, 2001).

Stan's visual abilities are expressed when he simulates his orchestral timpani role at home, as part of his music practice. He plans and plots his hand configurations on an imaginary timpani set as he does not own one, by moving his hands or visualizing their movements *(I have the part, I just imagine, I look at the tricky parts, and I just plot out which way I should do it)* (Stan, personal communication, February 17, 2011). Through this visual thinking, Stan would practice mostly notes, tuning, and hand movements to avoid entanglement during a hands crossover *(there are typically four physical drums… so you need to plot out, each drum has a different range, and you have to figure out, well, if I'm gonna get from these four notes, and I need another note very fast, which one of these am I going to use? you can't figure that out in real time, you have to plan it)* (Stan, personal communication, February 17, 2011).

Overall, Stan's engineering mindset is exhibited through his pattern-oriented, gestalt thinking, which is manifested in his music and mathematical worlds, as well as in social situations. His visual thinking is also manifested in his gestalt thinking (visualizing the big picture) and in his simulated music practice.

Ethan believes that his overall visual abilities were honed by music memorization *(I said, "that's from all those years of memorization, music memorization, that you have this way of* *storing graphic images–it's there, sometimes you don't even know it except when you have to pull it out")* (Ethan, personal communication, February 21, 2011). His ability to store and retrieve graphical representations is reflected in both disciplines of mathematics and music.

Ethan is capable of storing and retrieving graphical, aural, or kinesthetic representations of music by "dialing in" a piece of music *(I have memorized so many sonatas and concertos that I can dial up something if I'm stuck in the airport, and there's nothing to do, and I don't have a book and everything else, I can dial up a concerto or something that I've played… it can be quite joyful, it's a very, it's a wonderful feeling and I feel much better for it afterwards, I feel very satisfied, very complete)* (Ethan, personal communication, February 21, 2011). During this dial in process, Ethan can hear, feel, or visualize himself playing the music *(I can sometimes see the music)* (Ethan, personal communication, February 21, 2011).

In the context of mathematics, while overtired in preparing for an oral exam in a graduate math course, he scanned the pages of some sections without deeply studying them. When questioned on a theorem proof that required the use of mathematical equations from precisely these scanned sections, Ethan was able to retrieve their graphical representation, draw them on the board, and use them to prove the required theorem *(I'm standing at the blackboard under intense pressure, and what I'm seeing is the pages, I am seeing this two dimensional stuff with a lot of equations)* (Ethan, personal communication, February 21, 2011).

Overall, it is likely that Ethan's visual memory abilities, which have been practiced mostly in his music discipline, transferred from there to his mathematical and computer disciplines. This parallels his acknowledgement of the transfer of his gestalt-oriented thinking in music to his computer-science work.

In general, it is questionable whether Ernie's, Meg's, and Stan's visual abilities are related to their musical training. Although several studies, triggered by the controversial Mozart Effect study by Rauscher, Shaw, and Ky (1993), have reported positive associations between formal music listening and spatial/visual abilities (Hetland, 2000a) and between music learning and spatial/visual abilities (Hui, 2006; Schellenberg, 2001; Heltand, 2000b; Gromko and Poorman, 1998; Lamb and Gregory, 1993; Nelson and Barresi, 1989), the evidence for a causal link is still vague.

While the above studies show associations between music training and spatial/visual ability, neuropsychological research on music processing (Peretz, 2001) has advocated for modularity of music as well as for its individual aspects, such as the independent processing of melody and harmony in different parts of the brain.

3. Aesthetic Thinking

Aesthetic thinking has typically been practiced and valued in artistic rather than in scientific accounts. This bias, echoed in C. P. Snow's (1960) *Two Cultures,* is evident also through the numerous accounts of scientific creativity that barely mention aesthetics, and through research on aesthetics, which mostly explores the arts (Leder et al., 2004). Testimonials by known mathematicians and scientists like mathematician Poincare (Poincare, 1946), mathematician Hadamard (Hadamard, 1954), astrophysicist Chandrasekhar (Chandrasekhar, 1987), and biologist/physiologist Root-Bernstein (Root-Bernstein, 1996) speak to the appeal of aesthetic themes in their work and identify aesthetics as a motivator for their pursuit of science. Moreover, Root-Bernstein (2002) also claims that scientific inventions have the potential to evoke aesthetic responses similar to those evoked by the arts.

Although when thinking of computer programs, the idea of aesthetics does not naturally come to mind, the area of software programming has developed its own aesthetics over the past several decades. Knuth (1974) and Billington (1985) have raised aesthetic considerations in the writing of algorithms, programming languages, and programs, while MacLennan (2006) was equally concerned with design of computer-user interfaces. A collection of accounts by computer professionals (Lammers, 2006) on the role of aesthetics in computer science bears a resemblance to the role aesthetics plays in artistic domains, and often includes analogies to these domains (e.g., poetry).

In this section, I discover the occurrence, use, and meaning of aesthetics for musical computer-scientists and how it is manifested across their computer-science work and musical avocation.

Ernie perceives aesthetics in music-making through the expressive dimension he adds following his mastering of the technical aspect of a musical piece *(there's the technical piece and there's the emotional piece… you have to have the plumbing… once that's there then you can start thinking about expression and, okay, what am I trying to convey*) (Ernie, personal communication, February 16, 2011). This expressive element, created by Ernie and perceived by his audience, bonds Ernie and his audience *(emotionally it's very satisfying to be playing music… you can really connect with the listeners… it's just a very powerful sort of um, you know, way to connect with people)* (Ernie, personal communication, February 16, 2011). In this latter mini-narrative, Ernie positions himself as the intermediary between the musical piece and the audience, whose role is to present the beauty of the piece to the audience.

While Ernie's music discourse on aesthetics implies sequential layering of aesthetics on top of technique, his computer discourse exhibits a closer integration between the analogous dimensions of efficiency and beauty. Ernie believes that a software program can be written at the same time to be efficient as well as elegant, rather than ad-hoc *(I also think of engineering as sort of having a technical thing but then the result can be beautiful too… if you're programming something, there's an elegant way to do it)* (Ernie, personal communication, February 16, 2011). This resonates with Billington's (1985) idea of function following form, mentioned above. This sequential versus integrated distinction is likely due to the inherent aesthetics already embedded in music compositions, which a performer can tweak only to a limited degree. In software programming, however, designers and programmers have more freedom in introducing aesthetic effects from the beginning of the creation of the software program.

In addition to elegance in software design, Ernie is passionate about the artistic and humanistic aspects of computer science, especially from the user's perspective, aspects introduced to him while a student at the MIT Media Lab *(it was so exciting there, because the Media Lab is about computer science and art, or about how society "should" use computers, you know, they think about sorta how technology affects society and um people, you know, it's much more humanistic)* (Ernie, personal communication, February 16, 2011).

Ethan, too, perceives aesthetic beauty in music-making as well as in elegant software. He perceives the beauty of some music pieces through his discovery of their structural organization, especially while reading their score *(you can really spend a lot of time just looking at the notes and understanding the relationships)* (Ethan, personal communication, February 21, 2011). With such observations he discovered beautiful elements while working on Myaskovsky's cello sonata *(he has this sonata that he wrote that has these wonderful things in it… he has the melody playing along, and underneath it is this inverted sixth, parallel sixths being played, sometimes by the piano, sometimes by the piano and the cello, and the piano doing the melody… it kind of* *cradles the melody, and suspends what key it's in, it's like this melody is floating… it's quite magical the way it's done)* (Ethan, personal communication, February 21, 2011). Such discoveries of structural organization helped Ethan memorize music pieces for performances. Unlike Ernie, who positions himself in the music aesthetics discourse as agentive in adding aesthetics through his music expressiveness, Ethan positions himself more as a discoverer of aesthetics of music for himself.

Discovery and surprise have been explored as themes of aesthetics in both music and mathematics (Rothstein, 1995; Wannamaker 1991), and are present in the accounts of scientists and mathematicians when grasping something correctly and completely at once. According to Rothstein (1995), Mathematician Gauss has described his feelings about succeeding to prove a theorem after working on it for many years, as a "sudden flash of lightning" (p. 136). This kind of sensation has been compared by the mathematician, Jacque Hadamard (1954), to the sensation Mozart describes in his letter, seeing his symphonies as a whole in his mind before putting them down on paper.

Ethan's lexicon for expressing his appreciation of music aesthetics makes frequent use of the adjective "beautiful." He uses it when referring to performed music by cellist, Leonard Rose *(both beautiful pieces),* when describing the sound of the cello *(this is a really beautiful instrument and someday I'm going to take it up),* musical periods *(beautiful late Russian romantic),* and musical quality of composers *(he wrote some beautiful music)* (Ethan, personal communication, February 21, 2011).

From his experience in managing large teams of programmers, Ethan appreciates two aesthetic aspects in software development. The first aspect is the creation of general-purpose flexible programs *(it does the general case, it does everything, you know, they designed it up and* *down)* versus ad hoc programs that work only for a specific case *(it does exactly what you want and nothing else)* (Ethan, personal communication, February 21, 2011). The second aspect is the aesthetic organization within a software program, which enforces, for example, unified naming conventions and elimination of redundancies *(unless you've worked in really large software projects, you really don't get that exposure, how much you need organization and to be able to structure things in a certain way, and to um, understand that a particular function over here maybe quite similar to another one over here even though they look like they're different)* (Ethan, personal communication, February 21, 2011).

In contrast to Ethan who sees aesthetics in computer science only from the perspective of the software designer, and more like Ernie, Miro is aware of the aesthetics aspect as a user. This is as a result of his work on user interfaces, ensuring that the user interface is attractive and intuitive *(I was very much insisting that, ok, "To be usable it has to have this… a musician is going to demand that" The result was a program usable by many different kinds of musicians)* (Miro, personal communication, March 17, 2011).

Similar to the ad-hoc versus general-purpose aesthetic distinction made by Ernie and Ethan with respect to software design, Miro sees the ad-hoc versus robust distinction in the aesthetics of user interfaces, an aesthetics advocated by MacLennan (2006). Miro uses the analogy of the piano versus chord organ[120] *(you couldn't play Bach on them, it just wasn't capable of music of that quality)* to illustrate an interface that requires significant startup time but is robust, versus an interface with little startup time but is limited (Miro, personal communication, March 17, 2011).

Miro also believes that both music and computer science share aspects of art and craft. He agrees with Donald Knuth's (1974) suggestions in his book *The Art of Computer Programming*

[120] A kind of home organ with a keyboard and a set of chord buttons, enabling the musician to play a melody or lead with one hand and accompanying.

that computer science is also an art and not just craft, in the same way that known composer and music educator, Walter Piston[121] suggests that there is craft in music in addition to art.

Meg's sense of aesthetics in computer science is reflected in her concerns as a systems architect for both the designers and users of software systems. In particular, she is concerned about the architecture and user interface of huge, complex software systems like the genomic systems she works on *(it's big science… look at these big genomics projects, they have tons, dozens of people… if you can't express what you need, what's going on, why it's important, make people care about it and so forth, you're sunk)* (Meg, personal communication, April 2, 2011).

With her awareness of failures of some large software systems that were too rigidly constructed largely due to their not involving users in their design *(they couldn't expand gracefully, adapt to requirement changes),* Meg was set on designing a robust and flexible genomic system by involving the users (Meg, personal communication, April 2, 2011). Via multiple presentations, which interacted with the users of the system she developed, she acquired their requirements as well as presented them with the architecture, improving the labs productivity *(there I built a really large group and just, you know, that lab went from doing, you know, a few genotypes a week to billions a week. It was incredible and it was a software that I designed that helped them to be able to do that)* (Meg, personal communication, April 2, 2011).

Meg also developed aesthetic simplicity. With her aesthetics sensibility, which Meg believes she developed through her music performances, she carefully modulated and simplified her computer architecture presentation to her computer-ignorant audience of molecular biology scientists *(one of my executive coaches… told me that I always had to be very careful about*

[121] An American composer of classical music, music theorist and professor of music at Harvard University (1894-1976).

modulating the information to the audience I was presenting to, and I said, "well I know what that is, that's performing") (Meg, personal communication, April 2, 2011).

Similarly, when performing music for kids, Meg has always been sensitive to adjust and simplify her performance for their ability and interest *(if I'm performing a piece for kids I do it slightly differently, whatever, or I'd program it differently)* (Meg, personal communication, April 2, 2011).

Like the discovery and surprise themes of aesthetics, which were reflected in Ethan's musical aesthetics, simplicity versus complexity is another theme of aesthetics (Rothstein, 1995). In mathematics, simplicity is reflected, for example, with proofs, which use a minimum of additional assumptions or previous results. In music, simplicity is reflected, for example, through Classical era compositions that exhibit simplicity via their structural clarity and economy, like the classic sonata.

Overall, musical computer-scientists expressed various aesthetic qualities through the music they played (emotions, organization) and the computer systems they built (design elegance, user interface considerations, organization, simplicity, flexibility). In addition to expressing pleasure from the effects of these aesthetic qualities, these individuals also acknowledged their effects on improving usability (in music: bonding with listeners, music understanding, and memorization; in computer science: humanistic and artistic expression through computers, intuitive user interfaces, robust design of software systems, and modulated and understandable presentations), and therefore also productivity.

C. Bringing Music and Computer Science Together

In this section, I examine the work-leisure fusion process of musical computer-scientists who brought their worlds of music and computer science together in a variety of ways, leading to a wide range of outcomes. Throughout their fusion journey they have experimented with home and school projects, conceived of innovative ideas and invented products, become involved in training and education, and practiced in communities which fused the two worlds. They also introduced their musical instruments at their work or school environments, and were able to virtually bring their music to work through their mind.

The constellation of multiple roles throughout an individual's vocational, developmental lifespan has been examined by several researchers, including Super (Super, D., Savickas and Super, E., 1996; Swanson and Fouad, 1999), Gottfredson (Swanson and Fouad, 1999), Holland (Swanson and Fouad, 1999), Krumboltz (Patton and McMahon, 1998; Swanson and Fouad, 1999), and Bandura (Swanson and Fouad, 1999), and can be extended to avocational life as well. Assuming multiple roles, such as professional computer scientist and avocational music-maker, individuals occasionally create work-leisure fusion or spillover in which aspects of work and leisure are fused or spill over from one to another (Super, 1940; 1945; Adams and Stone, 1977; Haworth and Veal, 2004; Snir and Harpaz , 2002; Sharaf, 2008).

Following the fusion journey of musical computer-scientists in this study and my three-step analysis, the following themes emerge:

- Interdisciplinary creativity;
- Deeper understanding of the music discipline;
- Applying computers in music education and training;
- Symbolic and virtual fusing of the two worlds;

- Participation in interdisciplinary communities.

1. Interdisciplinary Creativity: Integrating Music and Computer Science into Innovative Conceptions and Artifacts

One way in which musical computer-scientists in this study have fused their computer-scientist and music-maker roles, was through conceiving and experimenting with integration ideas at home and school, resulting at times with state-of-the-art inventions at work.

In this section, I uncover the meaning of the fusion experience for Ernie and Sol who pioneered the creation of innovative computer-music systems, and for Miro and Delia who participated in the creation of such systems. This meaning, particularly for Ernie and Sol, is comprised of the fusion process itself as well as the special ingredients that likely enabled them to go through their challenging creative experience. As such, I will discuss their fusion journey in relation to these ingredients, which I have identified to be: team spirit, passion, diligence, persistence, motivation, courage, ambitiousness, knowledge, freedom to explore, sensitivity, occasional failures and compromises, and their freedom to pursue. Similar types of ingredients have been discussed by Edwards (2008) in his study of the catalysts that drive innovators to cross the line between art and science in various environments. Inevitably, uncovering these ingredients entails re-telling some of the participants' experiences and the associated, supportive narrative segments. When possible, to minimize such overlaps, I refer to previous analysis or data. Through the analysis of these ingredients, I also reflect on factors that could help enrich interdisciplinary creativity in a family environment, in educational institutes, at work, and in leisure environments.

Ernie combined the worlds of music and computers numerous times throughout his life as a youngster, student, and as a working adult. With each experience, he became more knowledgeable and fueled with passion about fusing the two worlds, achieving his ultimate goal of relaying the real experience of music performance to the rest of the world, through a computer simulation of this experience.

Curious to explore programming, Ernie began, in 7th grade, writing simple programs and teaming up with his computer-savvy friend to write a music program that would play notes whose representation was keyed as input data *(it was kind of like a real synthesizer*) (Ernie, personal communication, February 16, 2011). Within his toying activity, Ernie positions himself and his friend as independent thinkers who can make sense of the world based on their own personal observations rather than being formally taught *(learning and figuring out on our own… I would mostly do a lot of things kind of on my own and with friends, I didn't really take much with the way of computer classes at, in high school)* (Ernie, personal communication, February 16, 2011). His experimentations with the music program is the earliest stage in his fusion of the two worlds, and is analogous to the early play and concrete operation stage of the human development stages suggested by development psychologists Piaget and Szeminska (1941), evolving to become more abstract in Ernie's subsequent fusion activities. Leisure development theorist Kleiber (1999) and creativity experts Root-Bernstein, R. and M. (2001) see toying as an important discovery phase, in which one freely explores and experiments with emerging interests.

A collaborator, Ernie engaged in harmonious, reciprocal relations of learning with his friend. Ernie acknowledges their helping each other *(he taught me a lot of stuff and I had this book on machine language),* their joint brainstorming *(I designed, you know, designed it, and talked* *about it with my friend),* and credits both in the success of the project *(we got this program to work)* (Ernie, personal communication, February 16, 2011). Ernie's sharing in his exclusive leisure interests conforms to Erikson's (1993) view of the growing interest of children to relate to others throughout their playful progression, establishing a sense that his leisure interests and skills are well regarded by others.

His parents' support in financing his new Apple computer and music cards and their general nurturing attitude (see Ernie's story in the Data (Stories) chapter), provided additional validation for Ernie on his distinctive leisure interest, a positive reinforcement explored by leisure development researcher Kleiber (1999), and developmental psychologists Erikson (1993) and Dacey (1989b).

Driven by his passion for his clarinet music repertoire *(I was into it because I think we had played it in the band),* Ernie chose his current repertoire of Shostakovich's "Festive Overture" and the first movement of Beethoven's "Ninth Symphony" as input data for his program.

His persistence and diligence enabled him to literally integrate the two worlds of music and computers, keying in enormous amounts of musical data using ones and zeros *(every day after school I'd spend hours just typing in the numbers, you know, I'd look at the score, type in the note, you know, type the note in, type the duration value, there's - whether it was loud or soft, and um just did that for hours and hours and hours)* (Ernie, personal communication, February 16, 2011). His naïve, yet developmentally stage-appropriate programming approach of keying in his repertoire note by note, is in alignment with Fischer's (2006) skill-development theory. According to this theory, the child only sees the symbolic meanings about concrete aspects of objects like, "my program can handle playing A" and "my program can handle playing C," yet cannot create higher-order representations about generalized aspects of objects like "my program can handle all notes," entailing a general-purpose music program. Moreover, the flexibility and variability inherent in Fischer's (2006) web-based, skill-development theory can explain Ernie's advanced standings with respect to his clarinet performance skills, relative to his less developed computer programming skills. Ernie's persistence, diligence, and adventurous nature resurfaced later when re-submitting his MIT application after being rejected during early admission, and when requesting and being granted a music re-audition for enrolling in an important MIT music class (discussed in Ernie's story in the Data (Stories) chapter).

As risk-taking and an adventurous nature are one of the traits that contribute to a creative personality (Dacey and Lennon, 1998), failures are inevitable along with the desire to self-reflect (Dacey, 1989a). Ernie is self-reflexive of his own failures *(I learned some good early lessons about that, not that it always works or helps but… you always have to keep trying and keep working on it. I don't think I played very well. It was not a very good representation of what I can do. It's also important to kind of let people know if you care about something)* (Ernie, personal communication, February 16, 2011).

Becoming knowledgeable in signal processing through his participation in the hardware labs as part of MIT's research mentoring program, enabled Ernie to create a more sophisticated integration of the two worlds the second time around. This time, he developed a system that recognized pitch and harmonies of played music using Fourier Transformations. The role of academic institutions in skill development is well demonstrated in Ernie's life. First, as MIT housed a fairly extensive music department, an avant-garde scenery for a technology-oriented school, it enabled Ernie to carry on with his early leisure activity of clarinet performance. Second, it provided Ernie with a research mentoring program in which undergraduates were mentored by graduate students performing research in labs with state-of-the-art equipment *(it* *was all about creating chips and parallel architectures and multiprocessors and memories and connections between all of them… you really get to learn how things work when you have to, you know, put it together and build it yourself. So that was all really fun, also the labs were good)* (Ernie, personal communication, February 16, 2011). Mentoring of skills is advocated in Lev Vygotsky's (1978) scaffolding, a teaching strategy originated from his sociocultural theory in which a more knowledgeable agent, such as MIT graduate students, provides temporary scaffolds or supports to facilitate the undergraduates' skill development. As the students' abilities increase, the scaffolding can be progressively withdrawn. With scaffolding, Ernie's programming skills reached abstraction, the highest tier in Fischer's skills web. Perceiving the abstract notion of a general-purpose computer program, he built a Fourier-based music system that was more general and robust than his first system, as it could handle all pitches and harmonies. Although not Ernie's fault, the music system could not be fully demonstrated due to his partner's failure to complete the visual display portion in time.

With his growing self-confidence in his ability to integrate the distinct worlds of music, computers, and signal processing through the latter project, Ernie became assured also of the inner gratification he draws from accomplishing such challenging, musical computer integrations *(it was one of the first things that I did that combined things like that, and, and I really liked it too… from doing that, I kind of understood that there could be things, you know, in the world, related to computers and music, or signal processing, you know, that I found pretty exciting)* (Ernie, personal communication, February 16, 2011). Indeed, as soon as the signal processing and hardware projects fell short of granting him this inner gratification *(it wasn't really doing it for me),* his adventurous nature propelled him to further explore MIT's research space (Ernie, personal communication, February 16, 2011). The feelings of intrinsic reward, that Ernie initially sensed through his demanding hardware projects but lacked later on, may be alluding to his reaching the state of flow (Csíkszentmihályi, 1990), which typically occurs, among other conditions, when one is wholeheartedly performing a task for intrinsic purposes.

Crossing the line between the two disciplines the third time around was made possible through Ernie's discovery of the MIT Media Lab, which placed an artistic and humanistic lens on computer science. His encounter with researcher and pianist Mike Hawley and his Bosendorfer piano that could read and play MIDI input, changed Ernie's life.

Ernie's discovery of the Media Lab rewarded him with excitement and feelings of gratification *(it was a completely different world, it was so exciting there, the Media Lab is about computer science and art, or about how society should use computers… it's much more humanistic)* (Ernie, personal communication, February 16, 2011). With this discovery he became challenged again, and built with his researcher pianist mentor, a computer that sent MIDI input via a video camera that read music from a Lego-made, scrolling piano player-roll to the Bosendorfer piano to play.

Ernie's latter accomplishment in the Media Lab was a turning point in his professional life as he genuinely felt he combined the two disciplines into one *(it really sent me off on a new trajectory… it was a really pivotal changing point for me where I realized, "oh I can do computer programming and music together as one discipline,"… because up 'til then I had been doing computers and electrical engineering and I was doing music, and I was doing both of them and they were fun but they were separate, like parallel non-intersecting engagements, whereas here, they intersected)* (Ernie, personal communication, February 16, 2011). Reengaging in the fusion of music and computer science, although this time generating music rather than recognizing, as was the case with his former MIT project, has likely been instrumental in the creation of new types of skills for Ernie. Based on Fischer's (2006) dynamic skill theory, continuously differentiating and integrating skills along their development pathway causes the emergence of new skills that are qualitatively different. With his new skills, Ernie was able to produce new knowledge in the form of a visual music recognition system, an activity likely to be classified as high creativity by creativity researcher Craft (2001), or as domain-changing creativity by Csíkszentmihályi (1996). According to the skill transfer models of Perkins and Salomon (1992, 1988), and as evident from Ernie's subsequent projects, Ernie's continued practice of his new skills in additional contexts led to their abstraction, and consequently to their subsequent transfer and emergence as "similar" skills.

Once more, Ernie acknowledges his feelings of intrinsic rewards and self-gratification, this time from using his newly found knowledge and skills *(I was using skills from both and it was, it was really exciting)* and from the symbolism of Lego blocks in his creative life *(it was the music, and the Legos and computer science, it kind of all came together)* (Ernie, personal communication, February 16, 2011).

Moving on as an MIT graduate student, Ernie continued combining music with computers at MIT's Media Lab, with Professor Tod Machover, who ran the computer-music group,[122] a new context for combining the two worlds and practicing his skills. Ernie believes that this new context, in which he engaged in various aspects of creating music with computers, helped form his identity and brought him closer to his current career *(that really set me up to kind of be who I am today, which is completely combining computer programming, engineering and music…my profession is about combining the two together)* (Ernie, personal communication, February 16, 2011).

[122] The mission of the computer-music group at MIT Media Lab is to extend musical expression to everyone, from virtuosos to amateurs, and in the most diverse forms, from opera to video games. They accomplish it through the creation of boundary-breaking new music, often using new instruments and music technologies.

Ernie kept up with his clarinet playing in parallel to his fusion journey throughout his youth and academic life (see Ernie's story in the Data (Stories) chapter) as well as later in his life when he took the business risk to co-found his startup company Harmonix, directly contributing to the company's products.

Following his passion for the humanistic and artistic side of computer science, and his experience with computer-generated music, Ernie's Harmonix started making music videogames such as *Guitar Hero* and *Rock Band,* extending musical expression to everyone *(part of the appeal of those games was to try to simulate the feeling of performing music)* (Ernie, personal communication, February 16, 2011). These games relay the sensations of performing popular rock music to their users by mimicking features of playing real instruments. Performers could also sing along while playing, using controllers modeled after musical instruments *(even though you're not actually playing right, it's just, you're pushing some buttons on a plastic instrument, but there's something about how we did those games that makes you feel like you're playing)* (Ernie, personal communication, February 16, 2011). They could also score on their ability to match scrolling musical "notes" while playing mock instruments or on their ability to match a singer's pitch.

Ernie feels that part of his accomplishment at Harmonix is due to his own engagement with music-making and performance *(I can understand we've captured that feeling because I know what it's like to perform… that's where having music experience is very relevant to this particular job… I'm kind of able to make that connection between those two, you know those two experiences, one is the real experience, the other is a simulation of the real experience)* (Ernie, personal communication, February 16, 2011). Implied by Ernie's latter assertions is the transfer of the knowledge of "feeling" from the source domain of his real clarinet performance to the target domain of simulated performance. With his substantial music-performance skills and his computer-music fusion skills, Ernie possibly managed through analogical reasoning of structural similarities (Gentner, 1983; Holyoak and Thagard, 1989), as well as with scaffolding from Harmonix scientists like compare/contrast (Bransford and Schwartz, 1999) and hugging/bridging (Perkins and Salomon, 1992, 1998) to map his own perception of music performance to simulated performance with mock instruments.

Overall, Ernie's creative journey gave him the gift of power to extend his music-making experience to everyone. It also helped shape his current identity, by pulling together and interleaving his personal traits with his sociocultural environment, and his innate and acquired skills (discussed in the previous section).

Sol, like Ernie, was passionate about integrating his two worlds of music and computers, creating his ultimate invention–a computerized music-editor to facilitate the life of composers. Although unlike Ernie, Sol was born into a music environment of fame through his well-known pianist and composer father and was self-taught in both music and computer science, his creative fusion journey was likely facilitated by similar ingredients to Ernie's.

Sol's risk-taking adventurous spirit and exploratory nature as a rock- and mountain-climber *(I was reading about various adventurers especially in mountain countries… and indeed I did a little bit)* have been already previously discussed (see Sol's story in the Data (Stories) chapter) (Sol, personal communication, February 28, 2011). Similarly discussed are other ingredients that likely enabled his creative fusion: his intrinsic motivation both to practice the piano *(I seemed to have the music gene… I discovered that, that young ladies gathered around when someone played the piano… and partly a movie at the time about the life of Chopin that suddenly started me on the track of playing the piano)* and to learn about computers *(mostly I* *was amazed at the cleverness of it… the ingenuity that went into, and so I was interested "how did the damn thing work?")*; his independent thinking as a self-learner; his non-pushy, yet music-nurturing parents *(they were delighted that I was interested in music and understood music)*; his freedom to explore ideas at Lincoln Labs *(people at Lincoln had a certain amount of liberty, especially in the research group… to experiment around);* his sensitivity and preference for civil research over military projects; his collaborative work spirit *(I always chose the people because they seemed like they were fun and interesting people to work with)*; and his supportive and stimulating work mentors, especially his hill climbing pal, and his mentors at Lincoln Labs, especially Wes Clark *(my serious mentor in my field… he's been an inspiration for many people, I think in the field, who view him as a grand old man in the field)* (Sol, personal communication, February 28, 2011).

Mentors and leaders of creative teams in the workplace can foster team creativity, according to Mumford et al. (2002), with four key qualities: intellectual stimulation, inspiration by providing a vision, support, and freedom. As Sol concurs, his chief mentor held all these characteristics. He was intellectually stimulating *(he had an interest in neurophysiology, and that just absolutely blew me away);* inspired his followers *(when he suggested that he wanted to build a small computer that would be of use to people working in not only neurophysiology but other medical disciplines, I said "Wow, that's for me.");* was supportive *(he encouraged all of his people to be… multiply skilled);* and provided research freedom (illustrated in the previous paragraph) (Sol, personal communication, February 28, 2011).

Motivated by his composer father's poor memory when the time came to write down what he just played as he composed *(he couldn't remember where he started or how he got there)* and by his mother's life role as his father's scribe *(she was sitting at a little card table with the ah,* *manuscript, he would sort of dictate things to her),* Sol was set on exploring solutions (Sol, personal communication, February 28, 2011). With his enabling ingredients, and with both a computer and a piano at his Lincoln Labs office *(I thought to myself, "there must be some way in which computers can help in this process"),* he began his fusion journey, accompanied with disappointments and failures along the way (Sol, personal communication, February 28, 2011).

Motivated by the failure of his initial and simpler solution of making the computer record played music, as it was not useable by his father (*things got lost on the tape and he found rewinding the tape was just hopeless*), Sol began to explore more sophisticated solutions (*there ought to be some equivalent to a music type writer*) (Sol, personal communication, February 28, 2011).

Ambitiously, he attempted to develop a full-fledged music editor, by making his TX2 personal computer display the audio signals that came from his office piano using the computer's analog-to-digital convertor *(so I thought, "oh well I'll just play this stuff into the computer and then I'll write a program that will analyze it and print out the score … for the first time I really managed to bring my understanding of both music and of ah, and computers, what computers can do very closely)* (Sol, personal communication, February 28, 2011).

However, like the failed music display in Ernie's initial MIT music project, Sol's full-fledged music editor turned out to be more ambitious than expected *(that turns out to be an extremely naïve view… when I looked at the signals that had been recorded, it was, it was in the computer, I saw nothing but a jumble)* (Sol, personal communication, February 28, 2011).

Through this second effort, Sol realized the complexity of the music discipline *(I did not understand how complicated music was... it was essentially the same problem, of course, as speech understanding if you look at the sound waves of speech and trying to think how to analyze* *those is pretty complicated. So I got a book on the physics of music… then I understood how complicated even a single note is on a piano… I realized that your brain is doing a tremendous amount of work even on a single note, let alone on the structure of the music itself when there are bunches of notes. So I soon realized that was an impossible task and I tried to analyze the sounds waves)* (Sol, personal communication, February 28, 2011).

Not giving up, Sol tried to enhance his analysis of the sound waves, exploring the possibility of placing a sensor underneath the keyboard to detect when the piano keys are pressed, but failed again *(I eventually realized it was a hopeless* task*)* (Sol, personal communication, February 28, 2011).

Becoming aware of the complexity of this problem from other grand attempts to tackle it, he decided to abort this path *(that's an AI problem roughly equivalent to the speech problem... I wasn't interested in trying to pursue that because it wasn't something I was going to get done in my lifetime)* and take on a different approach (Sol, personal communication, February 28, 2011).

As clearly illustrated in Sol's attempts to fuse the two worlds throughout his creative journey, he, like Ernie, experienced failures, and was greatly self-reflexive about them. As with Ernie, failures are an inevitable part of a risk-taker's creative journey (Dacey and Lennon, 1998), and so is also the self-evaluative nature (Dacey, 1989a).

Compromising, at Xerox PARC, Sol and another researcher developed the Mockingbird, an interactive, computerized music editor that involved a human intermediary *(a program that ah, was something that was an amanuensis, ah was required a person to go along and ah, and put structure down on top of the raw material that we could gather and convert it essentially from a piano-role like structure into actual music score)* (Sol, personal communication, February 28, 2011). The core assumption in the design of the Mockingbird was that the composer who knows what needs to be done *(what is the melodic line, which chords go together, what things need to be beamed together… all that structure that really defines the essence of music)* will be able to interactively edit the raw output structure produced by the automated system (Sol, personal communication, February 28, 2011).

With the development of the Mockingbird, Sol reached the feeling that the two disciplines of music and computing came together in his life *(I really have two fairly separate lives really, the music and the computing, although they came together when I, when I was working on the music software at Xerox PARC, working on the editor)* (Sol, personal communication, February 28, 2011).

Overall, Sol's creative interdisciplinary journey began as an emotional tribute to his father and the class of composers he represented. However, its meaning gradually took turns and became a living testament to the complexity of the music discipline. This journey also helped shape Sol's current identity, by pulling together and interleaving his personal traits with his sociocultural environment, and his innate or acquired skills (discussed in the previous section).

Although not an inventor, Miro, too, combined his music and computer-science worlds, first as a student and subsequently as part of a team that developed a commercial, computerized music system. Unlike Ernie and Sol, Miro aspired to become a professional musician while a music undergraduate student, but changed his career aspirations soon after graduating, working as a computer scientist and acquiring his formal degree later on in his life. Like Ernie and Sol, he possesses curiosity, sensitivity, passion to explore and pursue, but displays only a moderate degree of diligence, motivation, ambitiousness, knowledge, occasional failures and compromises, and is not daring, persistent, or a team person like Miro and Sol.

Becoming knowledgeable in the Fortran programming language from a course he elected while a piano/percussion performance undergraduate, and observing in parallel the mathematical structure of music counterpoint rules he just learned *(you can almost see the mathematics behind it),* Miro put the two together to develop a computer system that represented these counterpoint rules *(I actually translated the rules of counterpoint into Fortran)* but did not get it to produce counterpoint harmonies (Miro, personal communication, March 17, 2011).

Miro, empowered and excited to apply his newly acquired programming tools, felt like a musician having a Steinway piano or a Stradivarius at his or her disposal *(there's this tool, and "oh let's see what I can do with it!" and "oh I can think of something to do, I'm going to try this!" Ok and then suddenly, ok so I've got this, I've got this kind of challenge. Can I make it do this? And can I do it so like I put in a counterpoint exercise, can it point out all the mistakes?)* (Miro, personal communication, March 17, 2011).

Sensitive to protecting the job security of his harmony teacher who taught him the counterpoint rules, he never disclosed to him his project of computerizing the counterpoint rules *(I wasn't sure if I really wanted to, because I didn't want to make him think he could be replaced by a machine)* (Miro, personal communication, March 17, 2011).

With his cautious and risk-aversion mentality *(I like to stay in one place. I like to, you know, live at home, I like to be at home every night. And I like to have a steady pay check),* Miro rejected music as his career and began his computer career with data entry positions, computer operator, and subsequently programming, also enjoying debugging *(one day my boss came into my office, and he had a huge stack of printouts. A stack of printout was like, you know, ten inches thick. And he said, "the computer crashed, find out why.")* (Miro, personal communication, March 17, 2011).

While acquiring formal knowledge in computer science through his master's at BU's MET College in parallel to working, Miro had the opportunity to combine his music and computer worlds once again, this time with a survey of computer music, in lieu of a thesis. As BU did not have any facilities at the time for sound synthesis, Miro provided a history of computer music along with examples *(I brought in some stereo equipment and actually played examples there)* and a presentation of notation for computer music using existing systems invented for musical typesetting for librarian purposes (Miro, personal communication, March 17, 2011).

Driven to get involved with more interesting projects than the ones offered by the companies he had pursued up to receiving his graduate degree, Miro moved on *(I found out at BU about other things that were going on that were far more interesting, more theoretical, not must accounting but things like compiler construction, and um, mathematical programming*) (Miro, personal communication, March 17, 2011).

After the language compiler project he worked on for NASA at an MIT-bred company failed *(at one time it was kinda considered an up and coming language… it turned out to be an extremely difficult language to write a compiler for)*, he courageously responded to an ad in the paper of a company, also an MIT spinoff, looking for a music programmer (Miro, personal communication, March 17, 2011). There he worked for a short time on his third integration of music and computer science, joining the end phase of developing a word processor for writing music.

Similar to Sol's attempt to write a full-fledged music editor, this project turned out to be more ambitious than originally perceived *(what they didn't know was the language of music is far more complex than, than the letters and words)* (Miro, personal communication, March 17, 2011).

Upon completion of this overambitious project, Miro moved on within the same company to his fourth integration of music and computer science, a Mac-based synthesizer controller that evolved to become the known Performer product, enabling music arrangement and performance with synthesizers and other devices using the then newly-developed MIDI standard. In this system, the computer digitally captured the sound commands sent from the sound source, making it possible to replay and manipulate the sounds by moving the captured sounds around graphically, like a piano roll on a screen.

Like his study counterparts Ernie and Sol, Miro was attracted to the human aspect of the computerized music system, focusing on its user interface *(I was very much insisting that, ok to be usable it has to have this, to be usable it has to have that, a musician is going to demand this, a musician is going to demand that)* (Miro, personal communication, March 17, 2011). With the user being his primary concern, Miro used data from Beethoven's and Chopin's music to help specify the required range of input for the system *(look, it's going to have to do 128th notes… it's going to have to do 28 against 7, because here in this Chopin prelude he's got, or Nocturne, he's got 28 tuplets against 7 tuplets)* (Miro, personal communication, March 17, 2011). Being a classical musician while his developmental co-partner was a Jazz performer, Miro believes they complemented each other with respect to their contributions to the system *(he was more into the performance, I was more into the composition… we approached it from different angles, we saw different things, and we were interested in doing different things with it)* (Miro, personal communication, March 17, 2011). Miro sees their disparity as a gain for the system *(the result was a program usable by many different kinds of musicians)* (Miro, personal communication, March 17, 2011).

Although Miro was an original member of the development team *(I was there at the beginning… I was there at the founding of this, at the invention of this)*, he was not officially credited for his contribution to the Performer product, as the rights to the product were released to his colleague and the product was eventually signed under his colleague's name (Miro, personal communication, March 17, 2011). Since many of his programming modules were under non-disclosure agreements and not intended to be seen outside of the company he worked for, he intends to develop his computerized music inventions in the future under the open-source code open to the public *(I've had a few ideas for products um, musical products, that if I'd had the time I'd do them on my own, and then I'd be able to point to people and say, you know, point to them and say, "Here's something I produced, here is a musical program I produced")* (Miro, personal communication, March 17, 2011).

Like Ernie and Miro, Delia, too, was introduced to the interdisciplinary notion of combining music and computer science in one system while at the university. With parallel undergraduate degrees in piano performance and computer science, Delia created a music program as part of her Master's degree in Information Systems, which, similar to Miro's, generated music conforming with counterpoint harmony rules in Palestrina style *(I decided to try to put those rules into computer rules, and that the computer, I will give him a theme and he will continue this theme, and generate music in this style)* (Delia, personal communication, May 5, 2011). Delia recalls her project as "exceptional," commended both by her mentor, an expert in AI and expert systems, and by her committee members who were intrigued with her final system demonstration that was accompanied with her own playing (Delia, personal communication, May 5, 2011).

Unlike Ernie, Sol, and Miro, who accomplished interdisciplinary integrations of music and computer science also in their work world, Delia settled for her integration at school.

2. Integrating Music and Computer Science: Leading to Better Understanding of Music

Throughout their integration journey, musical computer-scientists furthered their knowledge not only of computer science, but also of music.

Although Miro's company estimated the project of building their music-editing system to be a straightforward project *(it turned out to be a much more ambitious than I thought)*, thinking that if they have already done a word processor for words they can do it for music *(we've done word processors; it's just notes instead of words)*, the project turned out to be much more ambitious *(the language of music is far more complex than, than the letters and words)* (Miro, personal communication, March 17, 2011).

A similar observation is shared by Sol, whose Mockingbird program helps musicians understand the structure of music *(I saw what was going on when I studied various piano scores and realized that the notation system highlighted the structures and that that's what, that's what it was all about, that it's a "what-goes-with-what" is how I put it, things that are connected both laterally and vertically, ah that recognizing that those structures are the important ones in music, ah in the music notation system, and that that was the structure which the person had to lay on, and that once you had laid that structure on, then the computer can provide further help)* (Sol, personal communication, February 28, 2011). Also for Sol, as the builder of the Mockingbird, it was necessary to look at how music is structured *(especially piano music analytically and realize that because the piano is an instrument that can play many notes at the same time, that in fact what it's doing is emulating an orchestra or a, some group of musicians,* *and that each one has, or at least temporarily got a place just as in listening to a quartet, You know, the second violin sometimes plays, sometimes doesn't play, And you know picks up ideas, its got its own part and ah piano music really consists of multiple parts very often, and ah recognizing that structure was very important because ah, it was part of how we built the system to let the user superimpose that structure on the, on the sort of raw materials. And when I described that to some musicians, it was a revelation)* (Sol, personal communication, February 28, 2011).

Although Stan did not go through the experience of creating a music system to better understand music, his mathematical tendencies enabled him to perform a self-study on the well-tempered scale and the significance of the cycle of fifths,[123] which helped him understand the structure of scales and harmonies *(my mathematical abilities allowed me to do that, with more facility than I could have that, cause I could understand the whole ratios, and how, how are logarithms and things like that)* (Stan, personal communication, February 17, 2011).

3. Training and Educating: Using Music Technology

Although Meg did not develop computer systems that integrated music with computer science, she recently, with 25 years of experience as a computer technology executive, flute performer, and teacher, combined her music and computer-science worlds in the training and education arenas. Along with other faculty, she designed a music-technology workshop for music teachers, and delivered it in 2011 through the Boston Symphony Professional Development Program. The curriculum included the use of Sibelius software for writing music arrangements and musical notation; the use of media software suite like iTunes, iPhoto, and

[123] A visual representation of the relationships among the twelve notes of the chromatic scale (a musical scale with twelve pitches, each a semitone above or below another), their corresponding key signatures, and the associated major and minor keys.

GarageBand; African drumming; and an interdisciplinary curriculum on behavior management techniques for music teachers, and on Meg's presentation on Music relation to Science Technology, Engineering and Math (M-STEM). Her presentation, which included live demonstrations, addressed similarities between writing a software program and a piece of music, sounds variability, brain activity while improvising, pattern recognition connection to estimation and prediction, and the use of technology in music and the arts.

4. Bringing in Music to the Workplace: Symbolic and Virtual

Study participants also fused their two worlds of music and computer science by either physically bringing their instrument to their work or school environment, or by "dialing in" music while working.

Sol, Stan, Ethan, and Ernie brought along their instruments to practice, play and even perform, creating an atypical scene at their school or work place. The presence or use of their musical instruments at their work/school environment would sometimes stimulate their interest in exploring creative ideas of integration of the two disciplines, or at the very least expose them to such ideas.

Early on in his computer career, Sol, after learning of another scientist at Lincoln Labs who has a piano in his office, was granted permission by his manager to have a piano move into his office *(I agreed I would only practice at lunchtime and you know, non-work hours)* (Sol, personal communication, February 28, 2011). An unusual type of event, the Lincoln Labs security guards almost turned the movers away *(one of the guards called me and said, "there's a man here who claims he has a piano for you," and with disbelief in his voice)*, even though Sol arranged for the piano to be moved ahead of time *(I bought a used piano, a little upright)* (Sol, personal communication, February 28, 2011).

Placed in Sol's office, he would practice it while people would pop in and out, listening to his playing *(they got used to it after a while and they would just, you know listen, but they wouldn't gather around and sit around or anything, they would just listen to me practicing)* (Sol, personal communication, February 28, 2011). Sol admits that such a scene is a bit unusual *(I just simply thought "well that's what I'm going to do." Ah I, I was glad to be able to do it, it was nice to be able to practice at lunchtime, and ah, people seemed to enjoy it, I never got any complaints and ah, people said nice things about it)* (Sol, personal communication, February 28, 2011).

Sol attributes his innovative ideas and systems partly to the presence of the piano in his office. Having the piano in his Lincoln Labs office, which had a computer too, was a catalyst in brewing his ideas to put the two disciplines together *(I thought to myself, "there must be some way in which computers can help in this process*,"*… there ought to be some equivalent to a music type writer… in fact in Lincoln laboratory back when I told you I had a piano in my office, I actually decided, for the first time actually, put the signals, the audio signals from my piano into a computer. TX2 had an analog-to-digital converter on it, and so I thought, "oh well I'll just play this stuff into the computer and then I'll write a program that will analyze it and print out the score")* (Sol, personal communication, February 28, 2011).

Although Sol did not possess a piano in his office at BBN, he became aware that a group of BBN musical computer-scientists (e.g., Martin, a participant in the pilot study of this research) were instrumental in getting BBN to purchase a Steinert grand piano after he left the company in

1980 *(Martin and I were friends at that time, too, and I knew he played the piano)* (Sol, personal communication, February 28, 2011).

Stan, while a graduate student of mathematics at Stanford, used to display his music pastime by playing his recorder at the university's courtyard with a group of friends, including faculty from the math department *(we used to play, noon time, several days a week, just go out in the, in the court yard and play um, early music on recorder, four or five of us)* (Stan, personal communication, February 17, 2011).

Displaying his music talents as a percussionist with the Stanford orchestra, drew a member of the music faculty, a percussionist too, to consult Stan on mathematical issues *(he was always asking me math questions, about Fourier series, and things like that),* with Stan discovering later that he was the well-known John Chowning, inventor of the mathematics behind the synthesizer (Stan, personal communication, February 17, 2011).

Relieving himself from the temporary cultural famine he encountered while working at the Wright Patterson air force base in Dayton, Ohio *(they like to go to car races, and stuff I wasn't interested in… I couldn't find people I could talk with)* while taking a break from MIT *(there's a life, it's intellectual, there's books),* Ethan decided to pick up the cello, inspired by a known cellist with whom he played two years earlier (Ethan, personal communication, February 21, 2011). After a prolonged search for a cello teacher, he rented a cello and began practicing in the airfield *(I literally went out to the airfield and I would practice… and I would practice a couple hours a day)* (Ethan, personal communication, February 21, 2011). Due to his intense practice, Ethan made significant progress, which was recognized by his teacher *(I'd play the lesson, you know, the work for the week, and he'd say "oh that's very good, now next week…" and I'd say, "oh I did that too")* (Ethan, personal communication, February 21, 2011). Although Ethan quit the cello when he returned to Massachusetts, he vowed to get back to it at some point in his life, which he did at age 60 *(and I said, "someday I'll get back to it", and six years ago I did that…I sold my last company and I said "I'm gonna do some things that I have a little time to do," and one was cello)* (Ethan, personal communication, February 21, 2011).

Ernie, too, was actively pursuing his clarinet playing, performing with musical groups at MIT at the same time he pursued his undergraduate and graduate studies in computer science *(MIT has a, an amazing music program… I gave full, full recitals at MIT every year which was also a very important learning experience… I think I developed musically quite a lot, Um, I played a huge amount of chamber music)* (Ernie, personal communication, February 16, 2011).

Moreover, as the CTO of Harmonix, Ernie is disciplined about creating a strict daily routine of integrating his clarinet practice and group rehearsals with work, especially prior to concerts *(sometimes I have to have a rehearsal, say from noon until 2, and that's smack in the middle of work… I set up my calendar and I have travel time before the rehearsal and travel time after, so I usually have to take 3 hours off of work… I can come in, I do two hours of work, you know, which is usually meetings or emails or whatever, Um, then it's like "ok gotta go" take my clarinet, drive off to rehearsal… I show up and… it takes about 10 minutes to get going, and you're saying how are you and how's it going, and all this stuff, then we start working on the piece, and then you know we get into it and actually working and focused on it, Um and then after two hours I'm kind of packing up my instrument and going back to work)* (Ernie, personal communication, February 16, 2011). This integration means a combination of two different activities that add to his life *(but it's really this kind of wonderful thing, I mean, it's um, I don't think of it as bad, you know, I actually think of it as this nice, very different thing that I'm doing right in the middle of the day… it was this period of something completely different, you know, in* *the middle of the day, which is, which I find kind of nice)* (Ernie, personal communication, February 16, 2011).

The ability of virtually playing a piece of music while at work was something Ethan could do *(when I'm at work, I sometimes think about music*, sometimes *I can drag a piece out, play in my mind)* (Ethan, personal communication, February 21, 2011). He describes that process as "dialing in" on command *(sometimes I have a need to play something, and I just play it. And I feel much better for it afterwards, I feel very satisfied, very complete)* (Ethan, personal communication, February 21, 2011). He does it especially when bored *(I also do that in my mind, I can, I have memorized so many sonatas and concertos that I can dial up something if I'm stuck in the airport and there's nothing to do and I don't have a book and everything else… it can be quite joyful, it's a very, it's a wonderful feeling)* (Ethan, personal communication, February 21, 2011).

5. Creating and Participating in Computer-Music Communities

In addition to the actual integration of the two disciplines into one computer-based music system, Miro was also curious about the new discipline of computer music. He began investigating the history of computer music while a computer-science student at BU. In the 1980s, he became a member the New England Computer Music Association (NEWCOMP), serving for some period of time as its president and treasurer. Working with the organization's co-founders, Otto Laske (whom he already knew from a former workplace) and Curtis Roads, he produced several concerts of computer music each year in Cambridge, Massachusetts. By that time he was familiar with the field of computer music, from Lejaren Hiller's "Illiac Suite" to Max Matthew's music languages, and Barry Vercoe's work at MIT, and even programmed one of Finserv's computers to play music. Miro was also involved with NEWCOMP's concerts, preparing tapes for the competitions and assisting with setup, takedown, and stage management. One interesting concert was a live performance of "The Hands" by Michel Waisvisz, in 1986, in which the composer wore glove-like sensors on his hands, using them to control several digital synthesizers. Miro's prediction in the 1980s that all music in the future would be "computer music" (i.e., any music involving computers at any stage of production) came true. Composers, nowadays, compose with word-processing programs like Finale or Sibelius; performers load to and read from a Music Pad or iPad; musicians use recording studios with computers running Pro Tools for editing and mastering; music is released as a digital compact disc or directly to a distribution system like iTunes; and consumers uses iPods to listen to music.

Becoming known in the computer-science circles as an expert in computers integration with music, Sol was offered by his former Lincoln Labs colleague and a Harvard professor, a position at Harvard to teach computer design and research computers with music *(that would've appeared to be my sort of central interest)* (Sol, personal communication, February 28, 2011). Due to his excessive responsibilities, Sol declined Harvard's offer and joined BBN.

For the past decade, Sol has met many professionals including computer scientists and software engineers (like Michael Flexer of the Saint Michael Trio) who participate in the concert series he runs from his home on the west coast with his wife *(I've become involved in other endeavors these past few years, and ah, other musical endeavors, for example we've run this concert series and ah, that's taken a good deal of my time, just organizing that and arranging that)* (Sol, personal communication, February 28, 2011).

Overall, through most of their work-leisure fusion activities, these musical computer-scientists made science a valuable part of music as well as music a valuable part of science. In some sense, they have re-created the interdisciplinarity between music and science that prevailed with many scientists since Pythagoras's time (Fauvel, Flood and Wilson, 2003). These historical scientists (Pythagoras, Kepler, Mersenne, Euler (1707-1783), Fourier (1768-1830), and Helmholtz) engaged in the acoustic, rhythmic, and structural aspects of music, studying the presence of mathematics in sounds, and designing various tuning systems and musical instruments.

In conclusion, three main themes along with associated subthemes were identified across the life stories of the seven study participants:

1. Playing and performing with musical groups, through which individuals were inspired to play and perform, were socially engaged, bonded with friends and family members, achieved internal gratification, and acquired certain skills that facilitated their work;
2. Manifestations of similar thinking skills in both disciplines, including the ability to focus and be in the zone, the use of an engineering mindset including analytical and spatial/visual skills, and aesthetic thinking;
3. Combining aspects of music and computer-science disciplines in creative interdisciplinary innovations, in applications for training music educators, through a virtual fusing of the two worlds, and through participation in interdisciplinary communities.

The following final chapter summarizes the results of this study, discusses additional themes and potential implications, and suggests directions for future research.

VI. Chapter Six: Discussion

This chapter summarizes the results of the current study, identifies additional themes from the cross-narrative analysis, offers some insights from my personal experience as a musical computer-scientist, discusses potential implications of the study, and suggests directions for future research.

A. Results

In this study I have attempted to provide answers to the following three questions:

1. *What are the cognitive, social and cultural inclinations of computer scientists with a music-making avocation?*

2. *How are they capable of concurrently engaging in these two seemingly disparate worlds on a regular basis?*

3. *How is their concurrent engagement informing their thinking and learning paradigms at work?*

Through the participants' life stories and the thematic analysis of their narratives, I have arrived at the following answers to these questions. First, with respect to their inclinations, musical computer-scientists in my study tended, since childhood and throughout their lives, to participate in musical groups, often playing multiple instruments. In addition to serving as a music playground, musical groups provided them with a social outlet in which they bonded with classmates, work colleagues, and also made new friends. Playing and performing with these groups contributed to their identity, granted them with self-confidence, empowerment, and internal gratification. They were mostly self-motivated in their music practice and hardly experienced parental force. Their parents were involved only when needed, purchasing new instruments, chauffeuring them to lessons and rehearsals, and financing music lessons. In addition to music-making, these individuals enjoyed, in their childhoods, toying with building blocks, building car and airplane models, playing with mechanical objects, and were mathematically inclined, feeling that they like and were good at mathematics. As they were exhibiting both musical and mathematical affinities, these individuals faced career decisions as to the field they would pursue academically. While all entertained passing thoughts on becoming professional musicians, with some pursuing music with a formal degree at the university level, they all eventually settled on music, as their serious avocation accompanying their computer-science work, even with rehearsals, and other performance commitments sometimes conflicting with their work schedules. These individuals were also inclined to combine the two disciplines in various forms: creating innovative products in which computers facilitate aspects of music, educate music professionals in the use of computerized music-applications, practice their music at school or work, virtually play their music repertoire in their minds while bored at work, and participate in computer-music societies.

Second, study participants developed or were endowed with cognitive skills that are typically used in both music-making and in computer science, making it possible for them to concurrently engage in both disciplines. They admit to having the ability to focus and be in the zone in both disciplines. They use an engineering mindset which combines an analytical way of thinking (e.g., pattern-oriented thinking, structural thinking, gestalt thinking) with a spatial/visual way of processing information in both music and computer-science activities. They express aesthetic appreciation in both their music-making endeavors as well as in their writing of computer programs and user-interfaces. In addition, their personality traits of curiosity, courage, and diligence, combined with their passion, supportive family, school environment, and helpful mentors, provide them with the necessary grounds to explore and pursue such interdisciplinary engagements.

Third, in addition to sharing cognitive capacities across the two disciplines, study participants have acknowledged that their concurrent engagement has occasionally informed their thinking and learning paradigms at work. For example, their playing with musical groups has honed the collaborative skills they employ in work projects, their discipline of music practice has subsequently sharpened their ability to focus and be self-disciplined at work, and their musical performances have instilled confidence and empowerment in them, facilitating their confidence during work presentations. They also believe that their aesthetic appreciation for computer-science programs has developed through their development of appreciation for beauty in music, through their listening and playing. Conversely (though out of the scope of this study), their computer-science work activities and mathematical abilities sometimes informed their better understanding of certain aspects of music (e.g., Sol's Mockingbird explicating musical structures, Ethan's book-like readings of music scores, understanding of musical rhythm).

B. Additional Themes

In addition to the three major themes identified in the Thematic Analysis chapter of being in the zone, having an engineering mindset of analytical and spatial/visual abilities, and of having aesthetic abilities, there are several additional themes that emerged across three or more research participants. These include career conflicts that involve a consideration of a music career, affinity for languages, the important role of good mentors, self-motivation, and non-authoritarian parental support. In this section, I chose to discuss two of these additional themes: the theme of career conflicts, a theme that has been discussed also by Mishler (2004) in the lives of craft-artists, and the theme of affinity for languages.

As mentioned in the previous section, study participants have contemplated careers in music prior to or simultaneously with their pursuit of a computer-science career. For example, while Ernie did not choose music as a career prior to joining MIT *(I didn't think of myself as a professional musician at that point),* he improved musically in a significant way since graduating from MIT, and has occasionally entertained the idea of having a full-time music career (Ernie, personal communication, February 16, 2011). As such a decision would require him to quit his leadership position at the company he co-founded, he deserted that idea *(I love what I do here and I like the people that I'm with and… Alex and I are like the heads of the company, it's a 250 person company… it's kind of like leaving your baby, emotionally it would be very very difficult for me to leave here) (*Ernie, personal communication, February 16, 2011*).* He resolved this conflict by seriously participating in several chamber music groups that perform regularly, and being compensated monetarily like his music colleagues.

Unlike Ernie, Sol did briefly consider music as his career in the middle of his college years, although when younger he rejected people's ideas for him to become a musician like his father. However, with his parents' discouragement *(this horrified my parents, ah because they knew … that it wasn't the most thrilling kind of life actually)*, and his father's view of a performer being secondary to the profession of a composer, he gave in (Sol, personal communication, February 28, 2011). His decision was also combined with his own reservations regarding becoming a composer *(I was not cut out to be a composer),* not wanting to have the burden of being compared to his well-known father, and believing he was not equipped with the necessary foundations in music to pursue it academically (Sol, personal communication, February 28, 2011).

Delia, upon realizing that her mandatory military service may spoil her musical life (w*hich happens to a lot of musicians in Israel),* decided not to let music go and deferred her military service *(which is granted only to excelling high schoolers)* until after the completion of her music degree (Delia, personal communication, May 5, 2011). Along with her music degree, she also studied mathematics and computer science *(I said, if I was accepted to music, so why not to, to, to do them both)* as she was good at it, and realized the potential monetary rewards compared to that of a music career *(it was much wiser to go study mathematics, physics, and science then go and study music)* (Delia, personal communication, May 5, 2011).

Ethan's tentative idea of becoming a professional musician faded away during his senior year of high school after the Sputnik launch in 1957, which inspired him to study the sciences, and also as a result of holding a negative view of a musician's life *(I was working as a musician and a musician's life is pretty awful, and that if you're a performing musician, typically you're either making an awful lot of money or you're making no money at all. And if you're making no money at all, what you do is you go into teaching. And at that time in my life, I really didn't want to teach music, I just, I wanted to be a performer)* (Ethan, personal communication, February 21, 2011). Wanting to support his mother after his father passed away, he felt that going into the sciences and engineering would be the best thing financially. Indeed, as soon as Ethan started to work at Lincoln Labs, he no longer needed to play music for money, so he started playing the oboe voluntarily in orchestras. During his senior year as an undergrad at MIT, Ethan again had serious thoughts about music as a professional career, but decided to continue working with computers, thinking that music would be too risky for him.

Stan considered becoming a professional musician when graduating from high school, at the peak of his musical career. He soon rejected that thought *(in order to earn a living doing that, I would've had to be better at it than I was, and I wanted more to enjoy it than have it be the sole source of my income)* (Stan, personal communication, February 17, 2011).

Meg experienced several career changes throughout her life, starting as a professional flutist *(I actually never did anything but music from the age of fourteen until I changed careers… I was a kid professional musician)* (Meg, personal communication, April 2, 2011). Her unpleasant experience at NEC ended her desire to become an orchestral musician. After a busy period of chamber music performances she stopped doing music full-time, and kept teaching music for a while but was seriously thinking of a career change, which was reinforced by her husband being a musician, as she was going to be the main breadwinner. She eventually became a full time computer scientist, but took a long time to mourn her farewell from professional musicianship *(it took me a long time to sort of feel, you know ok about the fact that I was no longer, my identity was no longer, you know as a professional musician… it's like the artist and your personality are one. And this was a very scary thing, it was sort of like severing myself, in half, you know by changing careers, and um, I think particularly because of the fact that, you know I didn't stop doing music because I was terrible at music, I stopped doing music, you know because I had a lot of other obligations and I think I just didn't feel like a, a selfish enough person to make my children suffer, You know, had I been poor)* (Meg, personal communication April 2, 2011). It has been a long, painful process for Meg to enjoy music after transitioning from a professional to amateur musician, feeling that she is out of shape with the flute. But Meg finally enjoys music again *(without feeling like it's work, and actually going to concerts* *and enjoying somebody else sweat)* (Meg, personal communication, April 2, 2011*).*

Miro, too, experienced career conflicts throughout his life. Upon graduating with a music degree, he wanted to go into computers as he felt that a musician's life is not steady *(they have a very precarious life… I like to be at home every night)*, not financially rewarding *(I like to have a steady pay check)*, and the alternative of becoming a music teacher was not attractive either, neither was the option of becoming a piano accompanist (Miro, personal communication, March 17, 2011).

In time, as he got more into the computer profession, Miro began perceiving music as a discipline that one can get a lot out of, and began enjoying the fact that he can choose what to play, as opposed to professional musicians who are being told what to play. He also was able to demonstrate his talent in music to an audience, something he typically cannot do with his computer programs.

The second additional theme that emerged is exposure of study participants to multiple languages, which might correlate with their musical and mathematical modes of expression and with their general inclination and capacity to express themselves in different ways. Being bilingual from an early age, or having an affinity for languages, characterizes five of the participants. Both Ernie and Delia speak Hebrew, their native language, and English. Ethan, who grew up in a multiethnic neighborhood, studied four years of Latin during high school, one year of Greek, and three years of German at MIT *(when I got to MIT in those days you had to take a language, and you could either take a language, or if you spoke it well enough you took your humanities in that language, I took two years of humanities, it was all in German, the lectures, the books, the papers, the exams, everything was in German)* (Ethan, personal communication, February 21, 2011*).* Miro took three semesters of Greek while studying music at BU *(it's this* *fascinating language…)* (Miro, personal communication, March 17, 2011). Meg has always been interested in languages *(I'm also interested in literature. I've read literature in a couple of different languages, and I think that's like slightly unusual for an American)* (Meg, personal communication, April 2, 2011). She began speaking German and French in high school *(I really liked foreign languages*) and continued with them through college (*conservatory of course, has a big, big opera department, they had wonderful Italian, German, and French department … 'cause they had to have it for diction)*, which enabled her to go back to school later (Meg, personal communication, April 2, 2011). David and Martin, the two pilot study participants, also had affinities for languages, with Martin being a native Uruguayan.

C. Purpose of the Study–Revisited

In addition to my major task of bringing out the voices of professional computer-scientists with a music-making avocation, and uncovering the meaning they assign to their music-making, this study has helped me reflect on aspects of my life as a musical computer-scientist as well as a researcher and writer.

In my story, there are my parents who, following my elementary school recorder teacher's suggestion, spent their savings on a German Seiler upright piano, which I still play during my visits to Israel. There is also the "not letting go" calling, which led me to keep up with both disciplines even at the college level, studying simultaneously at the Rubin Music Academy and at the math/computer science department at Tel-Aviv University where I dashed back-and-forth from the music department far over to the other side of campus to the math/computer science department. In my story, there is a memory of an explicit choice to continue with a computer-science career, and a recollection of my rationale that my vocational choice would guarantee prestige and financial security, while music-making would grant me emotional balance. In my story, after moving to the US and pursuing my master's degree in mathematics/computer science, and while working on research and development of state-of-the-art computer systems that understand written and spoken language at BBN, I brought music back to my life. Teamed with a professional violist and a clarinetist, we practice regularly and occasionally performed at various institutions including the Museum of Fine Arts, nursing homes, schools, and numerous benefit concerts. Being exposed to Jewish, Hungarian, and Romanian music through my heritage, inspired me to bring into our trio's repertoire gypsy and Klezmer music, which we all embrace with joy. The level of complexity of the pieces we perform and the issues raised have equipped me with the skills required for refined musical teamwork, much like in everyday life and corporate teamwork. Being equipped with advanced mathematical thinking tools and computer technology from my undergraduate studies, and computational linguistics technology from my master's degree, I realized that formal tools like grammar, syntactic and semantic analyzers, pattern recognizers, and statistics could be useful for describing various phenomena of human communication, including natural language sentences, texts, dialogues, and music scores. I could visualize the music repertoire I studied and performed as knowledge structures that I could formally analyze and process, and music began to unfold as a language with formal structure and was no longer solely about emotion and expressiveness.

In my story, there is Professor Edith Krause, my piano professor, a wunderkind who studied piano with the well-known pianist and master pedagogue, Arthur Schnabel, and survived the Holocaust in the Terezienstadt concentration camp through her piano performances. She taught me self-discipline in practice and performance while providing me with tools that have helped shape my creativity in interpreting musical compositions. In recent travels to Israel, I have visited with Edith, who vividly remembers my duality with math and music.

The time I took off from my computer-science work to rethink my professional direction ultimately helped me reach my final decision to pursue my Ph.D. in the Interdisciplinary program at the Educational Studies department of Lesley University. During this hiatus, I took marimba and clarinet lessons, and taught mathematics at Brookline High School and Applied Discrete Mathematics at the University of Massachusetts' computer science department. At Lesley, where I have been exposed to qualitative research concepts and interdisciplinary discourses, I experienced a significant impact on my perception of what knowledge is, how it is constructed and how it is made public. My musical orientation has prepared me to carefully listen to narratives describing the experiences of my study participants, as well as to the presentation of my analysis of their narratives. My analytical mind as a computer scientist, combined with my new training as a qualitative researcher, has prepared me to analyze their stories, and to bring their voices out to the world, using the formal tools of research. My linguistic orientation in computer science has also enabled me to integrate sociolinguistic analysis to the analysis of their narratives in order to fully capture the essence of the phenomenon I am after. Finally, similar to the participants in this study, I, as a musical computer-scientist, also was able to explore the combining of the two worlds of computer science and music-making, through my research demonstrated in this study.

D. Anticipated Contribution of My Research

This research can motivate educators and educational institutions to encourage and support individuals with interdisciplinary interests, and calls for such individuals not to leave behind their artistic passions despite the role of pragmatism in their career choices. This research can also help educators better understand individuals who are attracted to or engaged in multiple disciplines, and can accompany scientific research on cognitive skills used in the disciplines of music-making and computer-science.

First, as is evident by the accomplishments of the study participants, being constantly stimulated within each discipline, as well as through the sharing and transfer of cognitive skills across their disciplines, this study demonstrates the rich lives of these individuals, their high sense of self, ability to give to society, and their occasional ability to reach creative peaks (e.g., perpetuating music culture and substantiating the importance of computer-science to the society). As such, this study can motivate educators and educational institutions to encourage and support individuals with interdisciplinary interests through the establishment and continuation of music- and art- programs in academic institutions. Moreover, academic institutions should offer programs designed especially for such combinations, in the same way they began offering other combinations like law and business.

Second, observing the stimulating and rich life of musical computer-scientists in my study, I believe educators should encourage rather than oppress parallel interests, enabling individuals to reach their full potential, even for the sake of sacrificing practice in a single area of study. Well into the thematic analysis phase, I realized my personal misfortune of having to keep my parallel interests a secret from my college piano-performance teacher in Israel, who believed in the sole devotion to piano practice, and who was not aware until my sophomore year of my parallel enrollment in the math/computer-science department. The study participants, who created a life where they didn't have to compromise and give up their passions, can serve as a motivator for future generations with music-making aspirations, to not give up or minimize their musical interests despite their pragmatic choice of a more stable and financially rewarding computer-science vocation, but rather combine them in parallel to their practical career.

Third, this study can help educators and mentors to better understand and support children, adolescents, and students who are attracted to and engaged in multiple disciplines, providing them with ideas for engaging these individuals. In particular, educators can discover learning experiences that make individuals with computer-science inclinations, happier, challenged, more productive and creative professionals through their practice and performance of music, and through combining the two fields in an interdisciplinary fashion. This study can also facilitate adult-education mentors and career-development professionals in guiding adolescents and adults with multiple interests through their education and career choices. It can also help educators better understand the impact of sociocultural factors such as family, educational environment, peers, and demographics on life choices made by these individuals, specifically on their career and avocational decisions.

Fourth, it is possible that some of the themes that emerged in this qualitative study can help reaffirm existing scientific (and neuroscientific) research on cognitive skills that are believed to be shared among disciplines, or provide new directions for such research. For example, it might be useful to test participants' admissions to their increased confidence and empowerment at work due to their extensive experiences with music performances.

E. Directions for Future Research

There are several directions in which I would like to extend my study. First, I would like to further the analysis of the additional themes outlined in this chapter, i.e., career conflicts that involve a consideration of a music career, affinity for languages, self-motivation, role of mentors, and non-authoritarian parental support. Second, I plan to introduce a non-spontaneous element into the study, in which I ask study participants to consider my interview questions ahead of time, in order to provide them with more time to prepare their reflections on possible reciprocal relations they have experienced between the two disciplines. Third, along with a more comprehensive sociolinguistic analysis of the narratives, I would also like to integrate aspects of the performed music, such as the type of instrument, genre, and venue into the thematic analysis. Fourth, it will be useful to investigate a younger age group to account for today's computer scientists. Similarly, extend the demographics and types of music (e.g., jazz) of the participants. Fifth, I am interested in integrating a quantitative component to this qualitative research study, which will attempt to substantiate the common notion that a significant proportion of computer scientists have affinities for music or hold musical avocations, as compared to the general population. Although Haimson, Swain, and Winner (2011) have concluded that mathematicians do not have above average musical skills, their study uses a control group of language doctoral students, which, as they themselves admit, may not have been an appropriate one, as language-oriented individuals may have mathematical inclinations as well.

Sixth, researchers in the fields of interdisciplinary studies, creativity, cognitive studies, or career-leisure development, may extend this study to individuals with other vocation/avocation combinations, beyond computer science and music-making. Such studies may reveal additional aspects of inclinations and capacities of individuals to hold on to multiple, different disciplines, and can thus provide such individuals as well as educators and educational institutions with guidelines for keeping them engaged, happy, and productive. For example, such studies may explore individuals with performance-oriented avocations (e.g., acting, athletics, or music) and the significance of such performance to their vocation.

Finally, while in this study I performed the thematic analysis manually, I plan in the future to integrate it with qualitative research software (e.g., *NVivo*[124]). For example, I am interested in applying this software to the narratives of the current study participants (as well as to those of the pilot study participants) for comparative analysis and to potentially broaden and/or deepen my thematic analysis.

[124] *NVivo,* is a qualitative research software which helps in the analysis and interpretation of qualitative data.

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Appendix

Institutional Board Review

LESLEY UNIVERSITY Let's wake up the world.℠

Institutional Review Board

29 Everett Street
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Tel 617 349 8426
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Office of the Provost

November 9, 2010

To: **Varda Shaked**

From: Gene Diaz, Co-chair Lesley IRB *Gene Diaz*

RE: Application for Expedition of Review: *The Meaning of Music-Making for Computer Scientists and Software Engineers with a Music-Making Avocation*

IRB Number: 10-019

This memo is written on behalf of the Lesley University IRB to inform you that your application for approval by the IRB through expedited review has been granted. Your project poses no more than minimal risk to participants.

If at any point you decide to amend your project, e.g., modification in design or in the selection of subjects, you will need to file an amendment with the IRB and suspend further data collection until approval is renewed.

If you experience any unexpected "adverse events" during your project you must inform the IRB as soon as possible, and suspend the project until the matter is resolved.

An expedited review procedure consists of a review of research involving human subjects by the IRB chairperson or by one or more experienced reviewers designated by the chairperson from among members of the IRB in accordance with the requirements set forth in 45 CFR 46.110.
Source: 63 FR 60364-60367, November 9, 1998.

Date of IRB Approval: 11/5/2010

Informed Consent Form

December 2010

Title of study: The meaning of music-making for computer scientists and software engineers with a serious music-making avocation

Principal investigator: Varda Shaked

Institutional affiliation of the principal investigator: Doctoral student in the Individually Designed Specialization of the Educational Studies Program at Lesley University.

Introduction: This study explores how music-making is situated in the lives of computer scientists and software engineers who keep serious music-making in the center of their lives. In particular I would like to understand the cognitive, social and cultural inclinations of these people to embrace two such seemingly different worlds and their capacities for doing so. Since you qualify as such individual, I would like to invite you to join this research study.

Background information: My research is motivated by the high proportion of "musical computer-scientists," the particular perspective taken by the research literature on the mathematics/science and music connection and by my own interdisciplinary experience with these domains. The research literature focuses largely on the math/science and music relations as reflected in the shared aspects of these disciplines (e.g., identification and creation of mathematical structures in musical compositions, mathematical aspects in tuning systems). However, it is short of exploring the cognitive and sociocultural processes that facilitate and encourage the individuals who concurrently engage in these disciplines. My research study attempts to fill in this gap in the literature and contribute to the understanding of the capacities and inclinations of these individuals to engage in music and computer science by giving them an opportunity to express their voices.

Purpose of this research study: The aim of my study is to discover and describe the meaning of the phenomenon of music-making in the lives of computer scientists and software engineers who persist with the practice and performance of classical music. I want to be able to enter these people's perspectives and lived experiences of this phenomenon and provide a rich textured description of their experiences

Procedures: In this study I will ask you questions about your engagement in music-making, work environment, career choice, turning points, educational background, sociocultural background, etc. I will audiotape, videotape and/or take a photograph of you. I may also ask you to observe you practice music at your chosen location, at your own discretion.

Possible risks or benefits: There is no risk involved in this study except your valuable time. There is no direct benefit to you also; however, the results of the study may be of interest to you.

Right of refusal to participate and withdrawal: You are free to choose to participate in the study. You may refuse to participate or to withdraw any time from the study without any penalty. You may also refuse to answer some or all the questions if you don't feel comfortable with those questions.

Confidentiality: The information provided by you will remain confidential. Nobody except for me, the principal investigator, will have an access to it. Your name and identity will not be disclosed at any time. However the data may be published in my dissertation and in journals or other publications without giving your name or disclosing your identity. In case I would be interested in disclosing your identity in any publication I will ask for your consent in writing, specifically for that publication.

Available Sources of Information
If you have any further questions you may contact the Principal Investigator, Varda Shaked, at 617 739 1964 or via email at vshaked@rcn.com.

Additional contacts, if needed:

Faculty Supervisor:
Prof. Linda Dacey,
Lesley University,
School of Education,
Tel: 617-349-8943
Email: ldacey@lesley.edu

Lesley University's Institutional Review Board (IRB):
Tel: 617-349-8426
Email: irb@lesley.edu

AUTHORIZATION
I have read and understand this consent form, and I volunteer to participate in this research study. I understand that I will receive a copy of this form. I voluntarily choose to participate, but I understand that my consent does not take away any legal rights in the case of negligence or other legal fault of anyone who is involved in this study. I further understand that nothing in this consent form is intended to replace any applicable Federal, state, or local laws.

Participant's Name (Printed or Typed):
Date:

Participant's Signature :
Date:

Principal Investigator's Signature:
Date:

Interview Questions (2-2.5 hours Interview)

General Background:

1. Can you tell me a little about yourself and your family's history, education, etc.?

Music in Youth:

2. How did you start your musical life?
3. Were you self-motivated, or was there parent involved?
4. How were you encouraged and supported in your musical-making activities in your youth?

Other Interests in Youth:

5. What other interests did you have in your childhood and youth?

Memorable Times with Music-Making

6. When did playing become important to you? How did it happen?
7. Describe times in which music-making has played a significant role.

Memorable Times with CS/SW-Eng/Math Work

8. And when did cs/sw-eng/math become important to you? How did it happen?
9. Share some memorable projects throughout your work in cs/sw-eng/math.

Involvement in Two Disciplines

10. When you are working, how often do you think about your music-making? What are these thoughts like?
11. When you are playing, how often do you think about work? What are these thoughts like?
12. How did/do you manage engaging in music in addition to your work load?
13. Both work and playing an instrument can be an individual process or a team one. Did/do you prefer one over the other? Why?
14. Has music-making been a continuous part of your life or is it something you pick up and let go? If the latter, what makes you give it up for a while and what makes you pick it up again?

CS/SW-Eng/Math Skills

15. What about your teachers and learning experiences? How did they impact your involvement in cs/se-eng/math throughout your life?
16. Can you discuss the various cognitive skills you have been developing and using at your work?

Music Informing Your Work in CS/SW-Eng/Math

17. Has your music-making informed or affected your cs/sw-eng/math cognitive abilities? If so, in what ways? Can you share with me some specific examples?

18. In what ways does your "music-making brain" interfere with your profession?

CS/SW-Eng/Math Informing your Music-Making

19. Have you found that your cs/sw-eng/math skill set has enhanced your music-making? if so, can you relate any specifics as to the process?

20. Have you translated or borrowed concepts/ideas from your cs/sw-eng/math professional activities to your music-making activities? If so, can you discuss these concepts/ideas?

Decisions/Conflicts/Career-Choices

21. Describe conflicts and decisions you've faced regarding your engagement with music.

22. Have you ever considered a professional career in music? If so, why didn't you choose that path?

23. What were your career choices throughout your life?

Music Learning experiences and Teachers

24. Reflect on teachers and learning experiences that impacted your engagement with music throughout your life.

Music Practice and Performance

25. How did/do you practice your music? Do you still take lessons? Do you play new pieces or stick to old favorites?

26. What cognitive skills are you using when practicing your instrument?

27. What kinds of music did/do you like to practice/play?

28. How does your music practice make you feel? How did/does it affect (e.g., improve) you life?

29. Did/Do you perform? How often and where?

Hypothetical Situations:

30. How do you imagine your life without your music-making?

31. What about without your cs/sw-eng/math work?

Final Questions

32. Do you see yourself as a person of "multiple worlds"? If so, in what ways?

33. Do you think that you are happier than your cs/sw-eng-math colleagues who do not play an instrument?