Creativity and Innovation Among Science and Art

Christine Charyton
Editor

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A Discussion of the Two Cultures

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Editor
Christine Charyton
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Foreword by Gordon Gee

E. Gordon Gee Ed.D, J.D., Ohio State University President 1990–1997, 2007–2013, Vanderbilt University 2001–2007, Brown University 1998–2000, the University of Colorado 1985–1990, and West Virginia University 1981–1985. Dr. E. Gordon Gee is president of West Virginia University and president emeritus at The Ohio State University.

We are living in the twenty-first century where the promise and progress of American society depends now more than ever on the research and educational opportunities created at our public universities. Today, true excellence in innovation will be achieved through collaboration and creativity.

The Ohio State University, as one of the most comprehensive institutions of higher education in this country, recognizes this reality. By connecting academic dots within the University, Ohio State is using its size to its advantage, and encouraging creative thinking across disciplines. Our scholars and researchers are taking a lead role in preparing students for a competitive global world, one where the race often goes not solely to the swift, but to the smart. Indeed, Ohio State has the exciting potential to use creativity to fulfill our great promise to the next generation.

This current moment is one of unparalleled potential for this University. I returned to Ohio State in 2007 for my second tenure as president, following service to institutions such as Brown University and Vanderbilt University. Since retiring from the presidency on July 1, I have continued to dedicate my endeavors to the mission of higher education. And, what an exciting time to do so.

Although the American system of higher education is known as the world's best, it can also be frustratingly slow to adapt to change. At the same time, change is imperative to its survival. That is precisely why our institutions of higher learning must encourage creative and critical thought in their classrooms and labs across the country. And, perhaps most important, we must practice what we preach.

I have always derived great energy from being around students. Their energy, potential, and capacity for change is truly contagious. As a university president, I served as a guest lecturer in a course called the Psychology of Creativity, wherein I discussed the upward trajectory of Ohio State from excellence to eminence. I also elaborated on my experiences in leadership and service. To be sure, this course presented an excellent opportunity to meet with students prior to their graduation and engage in a discussion about the impact that a quality education has on their lives.

Creativity and Innovation Among Science and Art: A Discussion of the Two Cultures merges transdisciplinary knowledge that is often encouraged, but not always rewarded. It is a thought-provoking work, insightful, articulate, creative, and smart. Its comprehensive scope undoubtedly will prove appealing to undergraduate students, graduate students, postdoctoral, premedical students, faculty, practitioners, and administrators alike, as well as to scientists, engineers, musicians, and artists. Its discussion and findings have broad implications on a range of disciplines, from chemistry, physics, neurology, and neuroscience to art therapy, music therapy, the scientific side of music, and the intertwining of art and science as integrative disciplines.

This book is written by accomplished authors from myriad fields of expertise, all of whom are faculty affiliated with The Ohio State University, The Ohio State University Wexner Medical Center and Nationwide Children's Hospital, in Columbus, Ohio. It is my hope that you read, enjoy, and celebrate the cultures and the diversity of this collaboration.

Foreword by Christine Charyton

Christine Charyton, Ph.D., Licensed Psychologist, Columbus, OH and Visiting Assistant Professor in the Department of Neurology in the College of Medicine at the Ohio State University Wexner Center.

I am very grateful to President Gee as a guest speaker in the Psychology of Creativity and as a contributor to this book. I am also incredibly grateful to all the book chapter authors who also contributed multiple guest lectures to my psychology of creativity class for my students for Psychology 662, 462, and 2462. First things first, I try my best to provide my students with the best quality educational opportunities including experiential hands-on learning. I dedicate this book to all my students, past, present, and future as well as my clients. I am grateful to Mike Racke and John Kissel for support of my transdisciplinary research. I am grateful for the opportunities at Ohio State University to teach, conduct research, and provide excellent service for topics I am truly passionate about. I am grateful for Paul Sanders and Tom Nygren for offering me the opportunity to teach a rich variety of classes, including the Psychology of Creativity at Ohio State University. I am grateful for the insights I have gained working under Psychology Department Chair Rich Petty and Psychology Department Vice Chair Ben Givens. I have learned that creativity can thrive in any environment despite violent opposition, squelchers, lack of resources, lack of genuine support, and lack of extrinsic rewards. True creativity is in the eye of the beholder. If we want to be creative, we can do so in any environment, despite obstacles, roadblocks, and impediments. As I tell my students, creativity is meant to enhance people's lives and is the vehicle for innovation. Without creativity, there would be no innovation.

Students in my class came up with the three key take home messages of my course, which I affirm. One, that creativity is a choice. We choose whether or not to use our creativity. We choose whether or not to be creative. Two, that creative people can thrive in any environment. Creative people thrive despite their environment. Three, that creativity can be taught. Creativity can be taught; however, the learner needs to want to learn. Teaching is a vehicle to inspire us to want to learn. Furthermore, learning about creativity and learning to be creative is a choice.

Just as the course is an elective and brought many students from all over the university from various colleges across the university, students chose to take this course. Over approximately 7 years, the course began at approximately 25 and the last class had approximately over 100 students. Despite the large class size at over 100, students still had experiential and interactive learning, which is important to understand creative, critical, and higher order thinking. I encourage faculty teaching such classes to use interactive, multimedia. The class and I used music, videos, dialog, and debating. Topics included the discussion of space habitation, travel to Mars, politics, the many benefits of capitalism, and the problems and costs of communism in relation to individualism and collectivism. Several guest speakers presented on art therapy, music therapy, creativity and music and the brain, creativity in physics, creativity in chemistry, art history, and others.

This book is meant to engage people from various backgrounds, educational levels, and disciplines. It is meant to engage conversation across disciplines. Hopes are to enhance the awareness regarding importance of creativity and innovation in society. Creativity and innovation are necessary for our path to economic prosperity, not only for the United States of America but for other countries from around the world. Hope you enjoy your journey with us across several integrated cultures in the sciences and the arts as well as benefit from our conversation, reflection, and future directions in the rich diversity and light of culture.

Preface

Creativity and Innovation Among Science and Art: A Discussion of the Two Cultures has 11 chapters and two forewords, one by President Gordon Gee and the other by Christine Charyton.

Chapter 1 contains a brief introduction to the importance of creativity and innovation in the United States and in the world.

Chapter 2 contains a section on creativity and the brain as well as music and the brain.

Chapters 3 and 4 include creative arts therapies: music therapy and art therapy, respectively. The aim is to discuss how creativity can be used as a therapeutic intervention.

Chapters 5 and 6 discuss creativity in science and contain how theoretical physics is creative as well as how chemistry can use creativity in the Research Experiences to Enhance Learning (REEL) program, respectively.

Chapter 7 discusses the application of creativity in engineering and how creativity and innovation are key components of engineering design.

Chapter 8 includes a discussion on musical creativity, improvisation, nonlinear dynamics, fractal analysis, and the scientific side of improvisation.

Chapter 9 includes the integration of science and art and how individuals may excel in both domains. Case studies of East and West are discussed including the Ukrainian culture.

Chapter 10 includes a discussion and reflection of the conversation. Key salient take home points are discussed by the participants of the conversation.

Chapter 11 includes the future directions for creativity and innovation in education and our given disciplines. Where do we go from here? How can creativity and innovation flower among the cultures?

Best wishes with your interests, passions, and dialog about the two cultures in science and art as well as other cultures.

Our conversation among the cultures in science and art…

To view and download our video of the videotaped conversation among us, go to: extras.springer.com.

Thank you to all the students in the Psychology of Creativity course for their questions that structured this conversation.

Special thank you to Segun Osiniusi for videography, as well as Segun Osiniusi, Caitlin Jones, and Jill Francis for attending, participating, selecting all the student questions, asking questions and engaging in dialog for our conversation as well as Dianne Charyton for administrative support.

Thank you to all the faculty serving as guest lecturers for my Psychology of Creativity class. We engaged in dialog about music and guest lecture experiences off camera, and on camera, we shared interesting conversation regarding the dynamics of creativity and innovation in our given fields and domains from the individual through societal perspectives. Hope you enjoy, are enjoying, and have enjoyed our videotaped conversation.

Dedication and Acknowledgments

Special gratitude to all my students. They are the true reason why we are at the university. Gratitude to my husband, John Elliott, for encouraging me to bring injustice to the attention of the readers of this book, discuss this fact, and support me to continue to shine beyond the face of adversity while making lemonade out of lemons. Gratitude to my dad, Alex Charyton, for teaching me to stand up for myself, advocate for myself, and stand up for what I believe in no matter what or how severe the opposition. Gratitude to my mom, June Charyton, for teaching me to believe in myself. Gratitude to both Alex Charyton and June Charyton for reminding me to believe in myself. Gratitude to my Aunt Dianne Charyton for support so that the conversation would come into fruition. I am grateful to Frank Farley for introducing me to the work of C.P. Snow and Edward O. Wilson, which has helped me validate my own career path. I am grateful for inspiration to overcome adversity and violent opposition and be resilient despite all obstacles. These sources of inspiration include the Ukrainian people, my entire family, family lineage and rich history, my husband John Elliott, my parents Alex Charyton and June Charyton, Nobel laureates Albert Einstein, Barry Marshall, and Gerty Cori all for overcoming adversity with strength, resilience, and beauty.

I am grateful for understanding that we are not void of pain and suffering and that these challenges bring us deeper meaning. I am enjoying my pilgrimage.

To all my students and clients and fellow Ukrainians for my journey with them with efforts to enhance their lives and make a positive difference.

Contents

Authors Biography

Christine Charyton Ph.D. is a Visiting Assistant Professor in the Department of Neurology at the Ohio State University Wexner Center in Columbus, Ohio and a licensed psychologist in her private practice in Columbus, Ohio.

Dr. Charyton's research encompasses the synthesis and unification of interdisciplinary knowledge and transdisciplinary science. Dr. Charyton focuses on the integration of psychology, neurology, and engineering with cognitive and learning interventions. Dr. Charyton has been actively working on the measurement and assessment of creative engineering design and cognitive risk tolerance.

Dr. Charyton specializes in the treatment of comorbid psychological and neurological conditions using cognitive behavioral therapy (CBT) in combination with mindfulness and positive psychology. Dr. Charyton's clinical research integrates interventional research with neuroscience and epidemiology.

Dr. Charyton is also a musician playing piano, keyboard, organ, and some acoustic and electric guitar writing and singing her original compositions and performing at venues in her band called *Cyd Peace* (see cydpeace.com). She is working in the studio on the release of her 6–8th CDs called Pilgrimage I–III to be available shortly.

Ted M. Clark Ph.D. earned his Ph.D. in Chemistry from the University of Michigan and is currently Assistant Professor in the Departments of Chemistry and Biochemistry at The Ohio State University. His interests as a chemical educator center on the inclusion of research experiences and student-led inquiry in undergraduate chemistry courses as ways to promote student development and learning in diverse areas, such as content learning, epistemological development, literacy and technology skills, and increasing student insights into the Nature of Science. As Associate Director of the REEL project, he has developed, implemented, and evaluated in-class research experiences in the area of Environmental Chemistry involving thousands of students at OSU and across the state.

Alejandra Ferrer Ph.D., MT-BC is a board certified Music Therapist practicing at Nationwide Children's Hospital in Columbus, Ohio. Dr. Ferrer holds bachelor and master degrees in Music Therapy from The Florida State University and a Ph.D. in Music Education from The Ohio State University. Alejandra has experience treating adults with cancer and psychiatric illnesses and infants and toddlers with developmental delays secondary to long-term hospitalization. Dr. Ferrer is an active presenter in regional and national music therapy conferences on topics pertaining to medical music therapy, program development, and integration of children with special needs in the mainstreamed music classroom. Alejandra is a member of the American Music Therapy Association and the National Association for Music Education. Dr. Ferrer is co-founder of Drum It! LLC, a community-based drumming program designed to promote health and wellness in the Central Ohio area.

E. Gordon Gee Ed.D., J.D. is President of West Virginia University and President Emeritus at The Ohio State University. He also serves as the Director of Ohio State's Center for Higher Education Enterprise, which focuses on research and policy initiatives aimed at improving student success in public higher education. From 1990 to 1997, and again from 2007 to 2013, Gee served as president of Ohio State. Prior to Ohio State, Gee led Vanderbilt University (2001–2007), Brown University (1998–2000), the University of Colorado (1985–1990), and West Virginia University (1981–1985). He has served for more than three decades in higher education and, in 2009, was named by *Time* magazine as one of the top-10 university presidents in the United States.

Gee is one of the foremost thought leaders in higher education governance and policy. In recent years, he has chaired several state and national commissions focused on improving student success. These commissions included teams that recast the funding models for Ohio's instructional and capital construction budgets, as well as a national commission on higher education attainment. Gee is currently leading a statewide review of the quality and value of Ohio higher education, and he continues his work on improving student success at Ohio State's Center for Higher Education Enterprise.

Anne Harding MAAT, ATR-BC is a Program Specialist and Art Therapist at the Ohio State University Wexner Medical Center providing inpatient and outpatient art therapy programming as part of the James*Care* Survivorship program. She currently serves on the Ohio State University Medicine and the Arts Board and is Chair of The Medicine and the Arts Roundtable. Anne has served on the board of Buckeye Art Therapy Association as Bylaws Chair since 2011. She regularly provides educational and experiential lectures on art therapy in a clinical setting and has presented at state and regional conferences. Anne also facilitates an art therapy group for a local drug and alcohol rehabilitation program for women. She continues to look for ways to incorporate innovative ideas and modalities to art therapy programming.

Anne is the co-author of a chapter with Patricia Schmitt on empowering survivors through expressive arts in J.L. Lester and P. Schmitt (Eds.), Cancer rehabilitation and survivorship: Transdisciplinary approaches to personalized care published by the Oncology Nursing Society.

Dr. Herbert Newton received his M.D. from the State University of New York at Buffalo School of Medicine. He completed his neurology training at the University of Michigan Medical Center, in Ann Arbor, Michigan, and a fellowship in Neuro-Oncology at Memorial Sloan-Kettering Cancer Center, in New York City. Currently, he is Professor of Neurology, Neurosurgery, and Oncology and Emeritus Director of the Division of Neuro-Oncology, the Esther Dardinger Endowed Chair in Neuro-Oncology, and Co-Director of the Dardinger Neuro-Oncology Center, all in the Departments of Neurology and Neurosurgery at the Ohio State University Medical Center and James Cancer Hospital. His research focuses on the general care of Neuro-Oncology patients, the diagnosis and treatment of epilepsy in brain tumor patients, and the use of chemotherapy and molecular therapeutics. He has authored more than 185 peer-reviewed journal articles and book chapters, and is the Editor or Co-Editor of six medical textbooks. He is a former Chair of the Neuro-Oncology Section of the American Academy of Neurology, and is a reviewer for numerous neurology, neuro-oncology, and oncology journals. In addition, Dr. Newton is a musician and bassist, and plays in the local rock band Grey Matter, which has been active in central Ohio for the past 7 years. He has also been involved in the OSU Medical School Music Program, and has formed several different bands with Medical Students and performed in the Medical School talent show—Nite Out.

Robert J. Perry Ph.D. earned his B.A. in Liberal Arts from St. John's College in Annapolis, Maryland and his Ph.D. in Physics from the University of Maryland in College Park, Maryland. He joined the faculty in the Department of Physics at The Ohio State University in 1987, where he is a Professor and Vice Chair for Undergraduate Studies. He was a National Science Foundation Presidential Young Investigator and is a Fellow of the American Physical Society. He is a nuclear theorist who has worked on quantum chromodynamics, the fundamental theory of the strong interaction, and currently works on the application of renormalization group techniques to produce precise, ab initio calculations for low energy nuclear phenomena. Such calculations have been a principal goal of nuclear theory since the 1930s. The low energy phenomena still requiring such ab initio understanding include all nuclear structure and reactions on earth, except those at high energy particle accelerators and a vast array of astronomical phenomena, including supernovae.

Chapter 1
Introduction

Christine Charyton

I do not teach anyone I only provide the environment in which they can learn.

—Albert Einstein

The only person who is educated is the one who has learned how to learn and change.

—Carl Rogers: former Ohio State University faculty

In today's economy, creativity and competitiveness are the economic drivers of innovation around the world (Florida 2005). Florida (2005) emphasized technology, talent, and tolerance, as "the 3 Big Ts," that lead toward creativity and innovation. Talent (human capital) is vital for most career positions that value and utilize creativity. We need, not only to, tolerate differences, but rather embrace diversity. Students need to think creatively to enhance the 3 Big T's in order to find employment, sustain their career development, as well as develop their own personal and economic success.

Creativity is a vital need that still tends to be overlooked, especially in science, yet alone the integration of science and art. This book encompasses creativity in multiple domains in science and art from across the university and university medical center. Creativity is discussed in the creative arts therapies (music therapy and art therapy), neurology, neuroscience and medicine (creativity, music, and the brain), Science, Technology, Engineering and Mathematics (STEM) (chemistry education, engineering education, theoretical physics, and physics education), music (improvisation and culture), and art (the integration of science, art, and culture). The application of creativity by innovation is discussed in engineering, creative arts therapies (music and art therapy) as well as neurology and other areas.

C. Charyton (✉)
Department of Neurology, Ohio State University, Wexner Medical Center,
Columbus, OH 43212, USA
e-mail: charyton.1@osu.edu

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Creativity is the vehicle in which innovation can come to fruition. We need to use our creativity to effectively prioritize needs for novel solutions. We sincerely hope that you enjoy your readings and recognize how creativity can be used for a greater good to solve everyday problems in various disciplines, your own discipline, and in everyday life.

The United States leads with innovation in the global economy. We all have an obligation to help improve the lives of the many, not only in the United States, but throughout the world.

Reference

Florida, R. (2005). *The flight of the creative class: The new global competition for talent*. New York: Harper Collins.

Chapter 2
The Neurology of Creativity: Focus on Music

Herbert B. Newton

Abstract Creativity has been a very difficult human quality to study, but is now beginning to be understood at the neurobiological level. The most recent theories suggest that the major lobes of the brain, in particular interactions between the frontal lobes and temporal lobes, are critical for maximizing the potential for creative endeavors. The neural circuitry of the limbic system, as well as catecholaminergic neurotransmitter pathways and their lobar interactions, is also important in the process. Music is one of the most creative and complex of all human activities and appears to involve numerous regions and pathways within the brain. The process of listening to music involves many specialized regions, including the auditory pathways, Heschl's gyrus, the planum temporale (PT), and auditory association areas. Musical performance involves coordination between the neuromuscular system while playing an instrument, with simultaneous and constant auditory feedback on the quality of the performance and the need for any necessary adjustments. The process of music perception while listening or performing requires acoustical analysis of pitch, melody, and harmony, the use of auditory memories, analysis of musical syntax and emotional responses, and many other functions, all performed over a matter of milliseconds in the dedicated musical neural networks in the brain. In addition, the brains of musicians and non-musicians are now known to be different, with musicians having specialized networks and connections as a result of formal musical training. The origins of music, as well as the anatomical and neurobiological underpinnings of musical perception, performance, and training, are reviewed in detail.

H.B. Newton (✉)
Departments of Neurology and Neurosurgery, Dardinger Neuro-Oncology Center, M410-B Starling-Loving Hall 320 West 10th Avenue, Columbus, OH 43210, USA
e-mail: herbert.newton@osumc.edu

H.B. Newton
Division of Neuro-Oncology, The Ohio State University Wexner Medical Center and James Cancer Hospital and Solove Research Institute, Columbus, OH, USA

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Keywords Creativity · Neurology · Frontal lobe · Temporal lobe · Neurotransmitters · Music · Neural networks · Functional MRI · Planum temporale · Music processing · Heschl's gyrus

2.1 Creativity: Definitions and Overview

For hundreds of years, the underpinnings of human creativity have been debated by philosophers, psychologists, neurologists, psychiatrists, and cognitive neuroscientists. To this day, a complete understanding of this complex and mysterious process remains elusive (Hennessey and Amabile 2010). Creativity has been very difficult to study in human subjects and, due to its abstract nature, has been very difficult to translate into plausible animal models. Although there have been numerous attempts at defining creativity, all of them fall short of describing the process as it applies across all disciplines, including basic science (e.g., physics, chemistry), medicine, architecture, art in all of its forms (e.g., painting, sculpture, drawing), music, literature, and film. From a broad, cultural point of view, a creative idea or activity can be defined as a concept or formulation that is both novel and useful (or influential) in a particular social setting (Hennessey and Amabile 2010; Perkins 1988). This definition allows for the "cultural relativity" of many creative ideas or activities, since some might be considered novel and brilliant in a primitive or backward society, but might not be considered so creative or important in a more advanced culture. In addition, it helps make the distinction between the truly creative individual and others that are merely eccentric or have aspects of mental illness. Although there is a correlation between creativity and some aspects of psychopathology (e.g., anxiety, depression, hypomania; discussed in more detail below), it is not associated with "full-blown" mental illness, such as schizophrenia, mania, or melancholic depression. Another definition of creativity, with applications to more scientific endeavors, has been postulated by Heilman (2005) in his book *Creativity and the Brain* and states that creativity is "the ability to understand, develop, and express in a systematic fashion novel orderly relationships" (Heilman 2005). This definition is very helpful in understanding the creative process in the scientific disciplines (e.g., physics, chemistry, medicine), where the creative mind is trying to explain new anomalous findings that do not fit in with the current paradigm, but has limited value when applied to more artistic pursuits such as painting or writing music.

Earlier neuroscientific concepts of creativity from the 1970s were dominated by the theory of "hemispheric specialization," in which the non-dominant hemisphere (typically the right hemisphere) was considered to be specialized for creative activity in all disciplines, as well as holistic pattern recognition (Hennessey and Amabile 2010; Hoppe 1988). This theory was developed out of neuropsychological study of patients after corpus callosum transection surgery for intractable epilepsy. However, the lateralization model applies poorly to language-based creative activities, since language is supposed to be mediated in the dominant hemisphere. In addition, later evidence suggested that maximizing the function of both hemispheres was more important for creativity than selectively activating the right hemisphere (Martindale 1999). Moreover, further brain lesion studies noted that

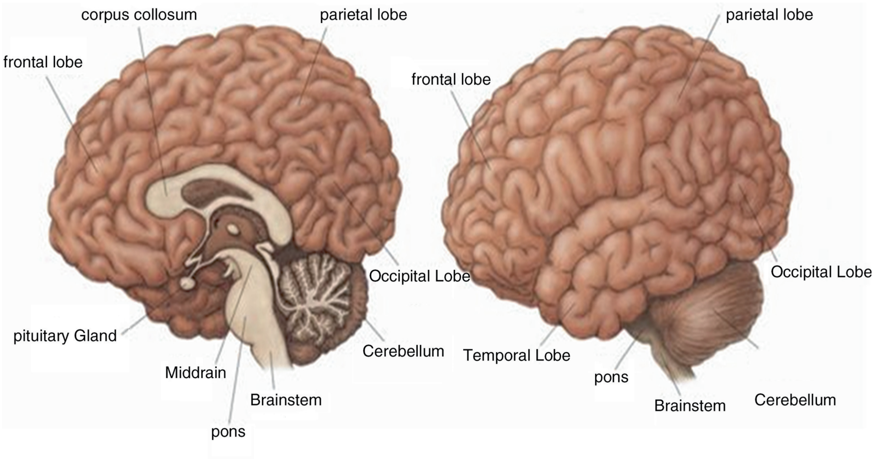

Fig. 2.1 Diagrams showing the medial and lateral surfaces of the brain, including the major lobes: frontal, parietal, temporal, and occipital, along with the cerebellum and brainstem

right or left hemispheric damage rarely affected creativity selectively. This is all consistent with a recent meta-analysis of hemispheric specialization and creativity, which did not find a predilection for right hemisphere activation during creative thinking and related activities (Mihov et al. 2010).

More modern theories on the neurobiology of creativity focus on lobar functions and lobar connectivity, in particular the interactions between the frontal lobes and portions of the temporal and parietal lobes (see Fig. 2.1) (Hennessey and Amabile 2010; Heilman et al. 2003; Flaherty 2005; Shamay-Tsoory et al. 2011; Abraham et al. 2012). Recent research has also implicated the limbic system, with its innate drive for human interaction and communication, as playing a role in creativity. Integral to connectivity between the different lobar areas, as well as for limbic system input into the frontal lobes, are the various catecholamine neurotransmitters expressed in neurons of these different neural networks. In particular, it is now becoming apparent that the degree of dopaminergic and noradrenergic activity, mainly from limbic and locus coeruleus projections into the major lobes, is also important for the creative process. In the following sections, we will review in more detail the various components of the lobar theory of creativity.

2.1.1 The Temporal Lobes and Creativity

Early on in the development of the lobar theory of creativity, it was postulated that the temporal lobe might be the neuroanatomical location for creative drive. This was based on the fact that hypergraphia, a compulsive drive to write, was localized to the temporal lobe in some patients with temporal lobe epilepsy, typically on the right side (Yamadori et al. 1986). Hypergraphia was considered a by-product of an overall decrease in temporal lobe activity. However, hypergraphia is even more commonly diagnosed in patients with mania and related states of hyperarousal. In patients with a mild form of mania and hypergraphia, there can be a high degree of creativity and novel idea formation. SPECT imaging studies in manic patients have shown an increase in activity in the right anterior temporal region, while EEG studies have shown a decrease in lower left temporal quantitative activity (Flaherty 2005). Mania is most likely to occur secondary to temporal lobe lesions on the right side, although other lobar brain lesions have been implicated (Braun et al. 1999). Frontal lobe lesions can occasionally induce mania and pseudomania, but typically show dysfunction of the temporal lobes as well on PET imaging. Although the correlation between manic states and creativity is most powerful for language-based fields, temporal lobe dysfunction can also result in the equivalent to hypergraphia in other creative endeavors.

For example, in some patients with frontotemporal dementia, a progressive neurodegenerative condition that results in frontal lobe and temporal lobe atrophy, there is a subset of patients (approximately 5–10 %) with predominantly temporal lobe damage that can develop compulsive artistic or musical interests (Flaherty 2005; Miller et al. 1998). Some of the patients developed these compulsive interests even in the absence of any prior artistic or musical tendencies. Damage to the superior, posterior dominant temporal lobe (usually left sided) near Wernicke's area can result in a receptive or Wernicke's dysphasia, in which the patient has increased speech output, along with impaired comprehension. Typically, the patient is unaware of the errors in the content of their speech. Non-dominant temporal lobe lesions do not impair comprehension, but are often associated with hyperverbosity and pressured speech, and may disinhibit left hemisphere language function (Braun et al. 2004).

Can the temporal lobes be assigned the site of creativity in the brain? Based on the information sited above, it is unlikely that creativity is mediated in the temporal lobes. Furthermore, since we know that the vast majority of temporal lobe efferents are inhibitory, it might be more accurate to say that the temporal lobes are the "region of creative suppression." For example, there are large temporal lobe efferent fiber bundles that inhibit the frontal lobes (see Fig. 2.2). And, most of

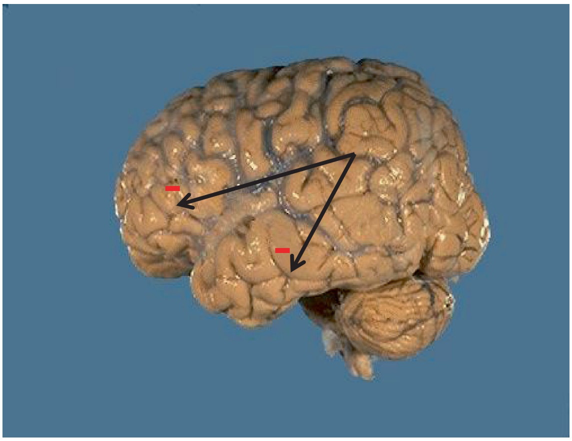

Fig. 2.2 Lateral surface of the brain, showing the frontal lobe and temporal lobe, with the inhibitory cortico-cortico connections in place, which are mutually inhibitory (see text for more details)

the above-mentioned conditions that were known to trigger creativity or creative drive (e.g., psychiatric conditions, neurodegenerative disorders) were doing so in the context of some form of disruption to normal temporal lobe function.

2.1.2 The Frontal Lobes and Creativity

In the lobar theory of creativity, the frontal lobes are hypothesized to play a more central role in the creative process. However, for many individuals, the frontal lobes are implicated in the setting of "creative block," when there is some form of frontal lobe dysfunction associated with an illness that is disrupting creative expression (Hennessey and Amabile 2010; Heilman 2005; Flaherty 2005). In general, a lack or loss of creative drive is much more common than an excessive creative drive. There is a strong correlation between creative block and frontal lobe malfunction from numerous conditions, including depression, anxiety, Broca's aphasia, abulic mutism, tumors, and strokes. The most common condition to result in creative block and frontal lobe dysfunction is depression. In the depressive state, there is a loss of motivation and cognitive flexibility, loss of interest in eating and sex (i.e., generalized anhedonia), and a loss of creativity. Imaging and functional studies are very consistent in demonstrating reduced or abnormal frontal lobe function, including functional MRI (fMRI), PET, SPECT, and MR spectroscopy (MRS) (Heilman 2005; Flaherty 2005; Liotti and Mayberg 2001; Wang et al. 2012; Liu et al. 2012). Once the depression has been successfully treated (e.g., anti-depressant medication, psychotherapy), frontal lobe function returns to baseline over time (Goldapple et al. 2004).

When the depressive episode has improved enough for motivation to normalize, there can be a reversal of creative block. Stimulant medication can also be helpful in treating depressive symptoms, including creative block (Flaherty 2005). Anxiety disorders, alone or in combination with depression, can also lead to frontal lobe dysfunction and contribute to creative block (Cannistraro and Rauch 2003). Recent studies show that anxiety can modulate hypoactivation in the middle frontal lobe and insular regions of the brain (Schlund et al. 2012). In this context, the creative block is similar to "performance anxiety" and is associated with a high degree of emotional arousal. Treatment of the anxiety (e.g., anxiolytics, anti-depressants, psychotherapy) should result in a reduced level of emotional arousal and improvement in creative block. Another frontal lobe condition with similarities to creative block, in particular writer's block, is Broca's dysphasia, secondary to damage in and around the pars opercularis region of the inferior frontal lobe (i.e., anterior speech area) (Heilman 2005; Flaherty 2005). Broca's dysphasia causes a selective deficit in speech production and fluency (including written language), along with a variable degree of word finding difficulty (i.e., dysnomia). Patients with Broca's dysphasia are very aware of their language deficits and speech errors and tend to be very frustrated and depressed by their limitations and reduced linguistic output.

A similar kind of frustration, anger, and depressed mood can be seen in patients with severe or prolonged writer's block. Lesions or damage within the frontal lobes outside of Broca's area can also cause depression and diminished speech output, along with other symptoms such as cognitive deficits, abulia or a lack of emotion, loss of motivation, and perseveration. Creative block can also be noted in patients with this kind of frontal lobe damage. The medial prefrontal cortical region appears to be very important for motivation and creativity, because damage to this area (e.g., brain tumor, stroke, hemorrhage, degenerative disease) can lead to amotivational, abulic states of decreased creative drive. For example, in a study of the frontal variant of frontotemporal lobar degeneration (fvFTLD), patients with the disease were compared to non-demented Parkinson's disease patients and normal healthy controls on a standardized test of creativity, as well as on tests of frontal lobe function (de Souza et al. 2010). The patients with fvFTLD were strongly impaired in all dimensions of the Torrance Test of Creative Thinking, in comparison with parkinsonian patients and controls. Poor creativity was strongly correlated with frontal lobe testing abnormalities and prefrontal hypoperfusion. The dorsolateral prefrontal cortex does not appear to be as important for creative drive and is more involved in working memory and flexible problem-solving abilities that can be applied to creative skills.

Normal frontal lobe function appears to be necessary for creative activity, but there are qualitative and quantitative differences between individuals in terms of how well the frontal lobes perform. In a study of regional cerebral blood flow (rCBF) in a matched set of healthy male subjects who scored either very high or low on a standardized creativity test, the baseline level of frontal lobe activity was higher in the creative group (Carlsson et al. 2000). In addition, there was a greater percentage of frontal increase in rCBF while performing creative tasks in the high creativity group. Overall, there was more activation (i.e., increased rCBF) in the bilateral prefrontal regions, left temporal lobes, and right cerebellum in the creative subjects. Transcranial electromagnetic stimulation (TMS) of the major lobes or deep brain regions is a noninvasive method with the ability to increase the activity in large groups of neurons (Hampson and Hoffman 2010). Preliminary studies have suggested that TMS over the frontal lobes can increase creativity in normal subjects when they are performing drawing and writing tasks (Snyder et al. 2004). Similarly, there are case report studies of patients that have had increases in creativity after undergoing subcortical deep brain stimulation with electrodes near the nucleus accumbens, a deep nucleus in the ventral striatum (Gabriëls et al. 2003; Flaherty et al. 2005). This is most likely related to connections between the nucleus accumbens and the frontal lobes, temporal lobes, and limbic system, and its supportive role in the generation of limbic drives.

Finally, it must be emphasized that the creative process often involves perseverance and persistence, independent of the domain in which the individual is creatively active (Heilman 2005). Goal-oriented behavior and persistence of activity are primarily mediated by the intact frontal lobes. Proper function of the frontal lobes allows the individual to plan and implement goal-oriented behaviors, but also inhibits and controls the more phylogenetically primitive neural systems, such as the limbic system. Inhibition of primitive biological drives and emotions is critical for goal-oriented and societally relevant behaviors, including creative endeavors.

2.1.3 IQ, Neurotransmitters, Limbic System, and Creativity

Early studies on the relationship between IQ and creativity demonstrated that they were only moderately related and that a person's IQ could not always predict their creative capacity (Heilman 2005; Torrance 1975). For example, when subjects with low IQs were tested for creativity, they consistently scored poorly. However, when subjects with high IQs were tested, there was a variable correlation with creativity. Another study looked at the relationship between the IQ and creative abilities of architects and found a poor correlation (Barron and Harrington 1981). It was concluded that for subjects with an IQ of 115–120 or higher, the IQ was not able to predict creativity as much as it does when the IQ is below 115. Therefore, there appears to be a threshold effect with IQ, and a person's IQ needs to be above a certain level in order to have sufficient intelligence to learn the knowledge set and acquire the skill sets that are necessary to be creative in a specific domain. Thus, intelligence is a necessary component of creativity, but once an IQ of 115–120 is reached, the motivation of the subject becomes the dominant feature that will drive creativity (Sternberg and O'Hara 1999). If a group of individuals with high IQs are all asked to develop creative ideas, the more highly motivated in the group will cultivate a larger number of ideas. Through the laws of Gaussian statistics, this will more likely result in a proportionately higher number of ideas that are novel and unique.

The neuroanatomical correlates of IQ and creativity remain elusive, but do seem to involve "connectivity" between nerves in the brain, as well as between different regions of the brain (Heilman 2005). Animal studies have demonstrated that the thickness of the cerebral cortex and the density of dendritic spines on cortical neurons are important for intelligence and performance (Rosenzweig and Bennett 1996). This type of augmented connectivity is seen in animals after being raised in "enriched environments." Having cortical neurons with amplified connectivity could increase the potential for more widespread neuronal networks necessary for faster learning and a greater capacity for knowledge. Enhanced connectivity between different regions of the brain is also thought to be involved in more creative individuals—between the right and left hemispheres, as well as between the major lobes, especially portions of the frontal, temporal, and parietal lobes. More widespread and enhanced neural connectivity would allow the creative individual to combine informational stores and representations of ideas in novel ways that were heretofore impossible.

It is well known that creative people have higher baseline levels of arousal and greater responses to sensory stimulation (Martindale 1999). Dopamine activity is known to decrease latent inhibition—which is a behavioral index of the ability to habituate to sensations (Swerdlow et al. 2003). Low latent inhibition can sometimes overload an organism with stimuli and is seen in various psychotic states. However, low latent inhibition is also a characteristic feature of creative individuals with high intelligence (Carson et al. 2003). The difference between the person with psychosis and the highly intelligent and creative individual is the ability to find patterns and order in the flood of sensory data, so it is less chaotic and disorienting. In addition to increasing baseline levels of arousal, dopamine activity can also induce focused creative arousal, which is highly goal-directed, and may be driven by

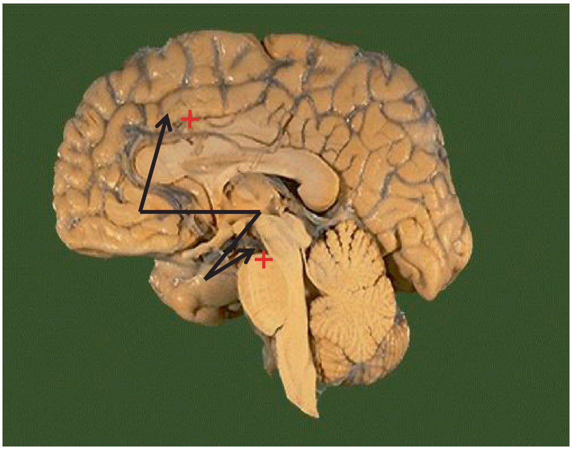

Fig. 2.3 Mid-sagittal view of the brain, showing the mesolimbic dopaminergic projections to the frontal and temporal lobes. These pathways facilitate the creative process by reducing latent inhibition (see text for more details)

mesolimbic dopaminergic efferents (see Fig. 2.3). Dopamine is also known to mediate reward-seeking behaviors such as gambling and cocaine addiction, as well as the appreciation for music and beautiful faces, and the need to communicate (Heilman 2005; Aharon et al. 2001). However, an excess of dopaminergic activity (e.g., L-dopa, dopamine agonists) can have deleterious consequences, including stuttering, coprolalia, hypomania, hallucinations, dystonias, and highly complex repetitive and stereotypical behaviors (e.g., assembling and reassembling an engine) (O'Sullivan et al. 2009). In contrast, dopamine antagonists, which are often used as anti-psychotic agents, are able to suppress hallucinations and stereotypical behaviors, as well as the free associations that are helpful in creative activity. One possible mechanism for the ability of dopamine to mediate focused reward-seeking behavior is a center-surround inhibition model (Mink 1996). In this model, dopamine is able to facilitate voluntary, goal-directed activity while simultaneously inhibiting competing behaviors and activities. This model has been well established in many motor and sensory systems within the brain, including the basal ganglia, retina, and visual processing centers. Dopamine may also play a role in creative discovery through its effect on novelty-seeking behavior, in particular through allelic variations of the D4 receptor (Keltikangas-Jarvinen et al. 2003).

The temporal lobes are thought to play a role in mediating the interactions between limbic dopaminergic activity, novel creative thought, and novel thoughts that are actually psychotic. For example, functional MRI studies have shown that schizophrenic auditory hallucinations—which can resemble a creative idea—selectively activate the temporal lobe (Shergill et al. 2001). In addition, metaphoric, cross-modal thoughts, and concepts are selectively impaired by temporal lobe dysfunction and damage (Jakobson and Halle 2002). Metaphoric thoughts and concept formation are critical for creative endeavors, since they depend on being able to detect analogies and relationships between phenomena that were previously thought to be unrelated. When metaphoric thoughts become extreme, they can pass into the psychotic spectrum toward delusional thought processes.

Many creative scientists, artists, and musicians claim to be most productive when they are in a relaxed, unstressed, and peaceful state of wakefulness. At these moments, the levels of brain and circulating catecholamines, in particular norepinephrine, are at reduced levels, which may be important for maximizing the size and connectivity of available neural networks (Heilman 2005; Heilman et al. 2003). As mentioned before, creativity and novel concept formation will be most robust when the number of neural networks, and connectivity between the networks is at its peak. With higher levels of norepinephrine and cortical arousal, the associative field of neural networks and their connectivity is suppressed, thereby limiting creative potential. This process is likely mediated through the noradrenergic projections from the locus coeruleus in the brainstem to the frontal lobes and inferior parietal lobes (Morrison and Foote 1986). The negative effect of catecholamines on the size of neural networks and cognitive flexibility has been studied and verified in animal models and human subjects (Heilman et al. 2003; Beversdorf et al. 1999).

2.1.4 Neurobiological Model of Creativity and Summary

A useful model that graphically represents many aspects of the lobar theory of creativity has been proposed by Dr. Alice Flaherty, a Neurologist at the Massachusetts General Hospital and Harvard Medical School (see Fig. 2.4) (Flaherty 2005). In this model, the *y*-axis is a continuum of dopaminergic activity that at the low end demonstrates slow action, emotion, and thought processes, and at the high end represents goal-directed and creative behavior. The *x*-axis is a continuum of lobar activity, showing normal frontal and temporal lobe activity in the middle, with abnormal frontal lobe activity toward the left and abnormal temporal lobe activity toward the right. If you move from the "Normal" region up the *x*- and *y*-axes (i.e., toward the hypothetical "zero"), you initially enter into a region of creative block, with mild frontal lobe dysfunction and reduced dopaminergic activity. The individual would experience a loss of creative ideas and novel concept formation, but would still be able to function in other spheres of activity. As you continue to move further up the axes, you pass this region and enter into a more severe state of profound frontal lobe dysfunction and loss of dopaminergic activity, and begin to display severe depression and/or abulia, with slowing of mentation, movement, and activity. Moving from the "Normal" region down the *x*- and *y*-axes, you initially enter a region of creative drive, with mild temporal lobe dysfunction and higher dopaminergic activity. The individual would experience improved creativity and idea formation, with otherwise intact function in other spheres. However, with this alteration of temporal lobe function, you would also be at higher risk for mild psychopathology, similar to many artists and writers (e.g., depression, bipolar disease, anxiety disorder). As you continue to move down the axes, you pass the Creative Drive region and enter into a state of severe temporal lobe dysfunction that, even with the higher level of dopaminergic activity, results in psychiatric impairment in the form of mania and psychosis. The model is not complete yet and would be more accurate if it was 3-dimensional,

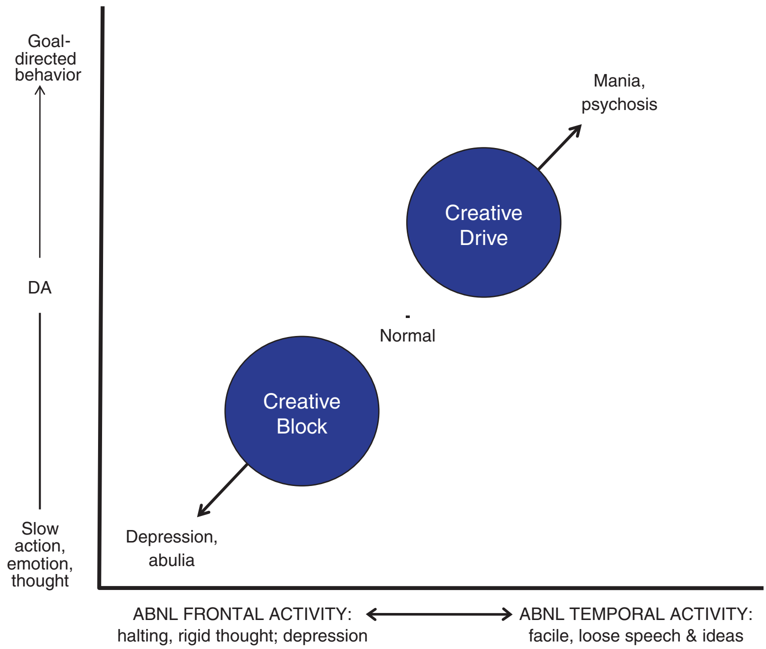

Fig. 2.4 Neurobiological model of creativity proposed by Dr. Alice Flaherty. The *y-axis* shows the continuum of dopaminergic activity, with higher levels being more inductive to creative activity. The *x-axis* shows the continuum of frontal lobe and temporal lobe activity, with the most creative combination requiring at least some degree of temporal lobe dysfunction. Adapted from Flaherty (2005), with permission from the author

so that frontal lobe function and temporal lobe function could vary independently (Flaherty 2005). In addition, it would allow for more accuracy if the lobar subsystems could also be incorporated into the model: frontal (orbitofrontal, dorsolateral, medial frontal) and temporal (lateral and medial).

In summary, creative drive will increase with mild-to-mild/moderate degrees of temporal lobe dysfunction in combination with increasing dopaminergic tone. Creative block increases with reduced or altered frontal lobe function in combination with decreasing dopaminergic tone.

2.2 Neurology of Music: Definitions, Overview, and Origins

Music is one of the most creative and complex of human endeavors, yet remains difficult to define since it can be described in many contexts, including that of musical listener, musician, social lubricant for various types of functions (e.g., religious, entertainment, educational, familial, medical, political), sociological, and evolutionary (Cross 2001; Huron 2001; Fitch 2006; Peretz 2006). One definition that has been offered by Cross states that music can be conceived of as individual abilities to process and respond to sonic patterns that are constituted by complex pitch and rhythmic structures (Cross 2001). This definition is very limited, is most accurate in the setting of the passive listener (e.g., an individual at a musical concert), and is less helpful for more social applications of music where it is used as an interactive medium in a group setting, or in explaining the individual who is driven to write and play music.

A broader definition of music proposed by Sessions suggests that music is sound that is organized according to principles of pitch, rhythm, and harmony, with musical timbres that allow for the differentiation between musical sound sources and musical instruments (Sessions 1950). No matter how it is defined; however, music has been an integral aspect of the human experience for millennia. Indeed, there is a consistent record for the presence of music making in human settlements from all over the world. Archeological evidence (e.g., prehistoric bone flutes) suggests that instrumental music has been present within human cultures for at least 40,000 years, and perhaps much longer (Huron 2001; Fitch 2006). There is also a controversial bone flute (made from a cave bear bone) from a Neanderthal burial site that has been dated to approximately 43,000 years ago (Kunej and Turk 2000). If this bone flute is legitimate, it would suggest that instrumental music has origins in the common ancestor of Neanderthals and Homo sapiens—Homo heidelbergensis—dating back more than 500,000 years ago (Tattersall and Schwartz 2009). However, critics of this research have suggested that the artifact was not a flute, but instead an ordinary bone that had puncture marks from the teeth of a predator. Nonetheless, the presence of human bone flutes from 40,000 years ago implies that the use of flutes and other instruments made from easier to manipulate and less well-preserved materials, such as reeds, wood, and sticks, would likely predate them by thousands of years (Huron 2001; Fitch 2006). It is also very likely that the use of rattles, shakers, and drums predate the use of bone flutes, which are somewhat complicated, by many thousands of years (some authors estimate by another 50,000 years), since they are ubiquitous instruments in hunter-gatherer societies from all over the world (e.g., American Indians, African tribes, Polynesian tribes). Furthermore, many authors also assume that vocalizations, or some type of crude singing, were the first form of music ever produced by individual humans (e.g., mothers singing to infants) and within human societies (e.g., singing as ritual in religious ceremonies or in preparation for battle). Singing as a form of music is estimated to predate instrumental music by 50,000–150,000 years using conservative estimates, and even longer by those researchers who feel that human song evolved before or simultaneously with speech (see discussion below). Based on the data above, it can be estimated that human music making came into existence from 100,000–250,000 years ago, and possibly much longer.

The long-standing history of music has lead to many theories about potential evolutionary aspects of music, and how it might have evolved within the human brain in a similar fashion to language. Language is a universal human characteristic—all humans are able to acquire language, unless they are suffering from a pathological condition or severe social deprivation. The acquisition of language requires exposure to, and engagement in, linguistic interactions within a time-sensitive period, generally considered to be from just after birth until approximately 4–5 years of age. The use of language is a specifically human ability, since it is not acquired spontaneously in any other species and only in rudimentary fashion by our closest primate relatives (Pinker and Jackendoff 2005). There are also very specialized regions of the brain that mediate language function, mainly lateralized to the left hemisphere and involving networks that incorporate Broca's area in the inferior frontal lobe (Brodmann area 44) and Wernicke's area (Brodmann areas 21 and 42) in the inferior parietal lobule.

The structural and linguistic aspects of language are universal (e.g., phonology, morphology, syntax, and semantics) and transcend all cultural, social, and societal barriers. It is also clear that the acquisition of language provided powerful evolutionary advantages for humans, in terms of increasing their ability to communicate to one another and develop large and complex social structures, all of which would have significant survival value. There are clear similarities between language and music, such as the presence of a hierarchical structure (syntax vs. harmony), a vocabulary (words vs. chords and intervals), tonal properties (inflection vs. timbre), and temporal features (prosody vs. rhythm). However, despite the substantial overlap between the neurobiological "design features" of music and language, there are also important differences. For example, language is able to "convey an unlimited number of propositional thoughts or 'meanings' with arbitrary specificity," while music is more limited (Fitch 2006). In addition, the ability to play music (or sing) does not have a "critical" or time-sensitive period similar to that of language acquisition, although it is true that most professional musicians started playing while very young (i.e., typically before 8 years of age). However, it is still possible to become quite proficient at playing instrumental music, even when the initial learning and "skill acquisition" do not occur until the teenage or adult years. Furthermore, music does not have the same body of structural comparative data, or cross-cultural and cross-societal universality, as that of language. Anatomically, there are no regions of the brain specifically evolved to mediate critical musical functions, as there are for the production and processing of language (i.e., Broca's, Wernicke's). As we will discuss later, the neurological processing of music is much more diffuse and involves numerous regions within the right and left hemispheres of the brain.

In spite of the differences noted above, is it possible that music, in the form of primitive or crude vocalizations and song, could have predated spoken language in humans and been an evolutionary predecessor? Indeed, this theory has been proposed by numerous investigators, including Darwin and Livingstone (Huron 2001; Fitch 2006). In the late 1800s, Darwin suggested that a primitive song-like communication system may have been a precursor to human language and been adaptive for the "progenitors of man," so that modern music might be a behavioral fossil derived from this past system (Darwin 1871). Based on this hypothesis, humans would have passed through at least one prelinguistic communication system or "proto-language" since our split with chimpanzees and before attaining full modern language (Arbib 2005; Masataka 2009). Over the course of this 5–6 million years of evolution, different selective pressures and forces would have driven different components of modern language capacity.

The hypothesis of a shared ancestral precursor of music and language is quite parsimonious, in that it recognizes many shared features of language and music, while allowing for the evolution of their differences, in particular the development of semantics in language, in a straightforward phylogenetic sequence. It is also consistent with the greater individual variability in music-making skills of modern humans (which are no longer strongly selected) in comparison with language skills (which are still under powerful positive selective pressure) (Judd 1988). In the field of comparative biology, there is strong evidence that music-like communication systems can evolve relatively easily (e.g., three different types of bird songs in birds, whale song, great ape drumming), while a complex communication system that allows for the ability to convey arbitrary meanings has evolved only once, in the form of human language (Fitch 2006). Therefore, a hypothesis that proposes that complex vocal signals (i.e., song) evolved first, followed by the attachment of meanings to those signals at a later time, are quite elegant and consistent from a comparative viewpoint (Fitch 2005). If the musical proto-language hypothesis is valid, then questions regarding the modern utility or purpose of music are moot. According to this hypothesis, proto-music might once have had specific functions (e.g., courtship, territoriality), but in the modern era exists only as a remnant, with its critical functionality replaced by the use of language.

In addition to an evolutionary process in which music (in the form of primitive vocalizations and song) might have evolved as a precursor to spoken language, what other evolutionary pathways have been proposed and discussed as possible evolutionary origins of music (Cross 2001; Huron 2001; Fitch 2006; Peretz 2006)? Several broad categories have been proposed, including *mate selection*, *social cohesion*, *group effort*, *perceptual development*, *motor skill development*, *conflict reduction*, *safe time passing*, and *transgenerational communication* (Huron 2001). *Mate selection* refers to the possibility that music making may have arisen as a courtship behavior and improved the ability to attract a good partner. *Social cohesion* refers to the ability of music to contribute to group solidarity, promote altruism within the group, and increase the effectiveness of collective action (e.g., hunting, defense). *Group effort* refers to the ability of music to contribute to the coordination of group work, such as the creation of living quarters or building a ship. *Perceptual development* refers to the idea that listening to music might provide an "exercise" for hearing and might improve the perceptive abilities of individuals in the group. *Motor skill development* refers to the ability of making music (especially instrumental music) to improve and refine motor skills. *Conflict reduction* refers to the possibility that the use of music in social situations might have led to a more relaxed environment, with less interpersonal conflict. *Safe time passing* refers to the possibility that playing music or listening to music might have provided a benign form of time passing, as human social groups became more efficient at gathering food and had more free time. *Transgenerational communication* refers to the ability of music (e.g., folk songs) to convey socially relevant history and other information over long periods of time.

Of many theories noted above, the ones that suggest an important role for music in the larger sphere of social interaction are likely to be the most significant (Huron 2001; Fitch 2006). Music is a very powerful means to establish behavioral coherency in large masses of people, which could easily have had survival value in the more primitive past (Roederer 1984). In addition, music might have originated as a means for large-scale social bonding, with the ability to synchronize the mood of many individuals in a large group, thereby preparing the group to act in unison to accomplish socially relevant goals. The mood synchronization effect of music could serve many socially important functions that would have evolutionary implications, such as having a calming effect in the setting of social gatherings where group harmony and bonding were important (e.g., wedding, funeral), or in raising spirits and aggression levels in preparation for a war party or to protect home turf against warring tribes. In these situations, music is playing a social role in its ability to help define a sense of group identity and common purpose, by synchronizing individual moods to serve the larger goals of the group. Along these same lines, recent work by Fukui and others has shown that listening to highly favored music can lead to a lowering of testosterone levels in males (Fukui and Yamashita 2003).

This finding has social and evolutionary significance, in that lowering of testosterone levels would likely result in less aggression, less conflict, less sexual confrontation, and less sexual competition, thereby engendering more group cohesion. Similarly, it has been suggested by Freeman and others that listening to music can induce the release of oxytocin in the brain (Huron 2001; Freeman 1995). It is known that oxytocin is important for pairing life events with strong memories, especially those involved with major limbic activation, such as trauma, sexual activity and orgasm, ecstasy, and strong emotional arousal. In addition, the release of oxytocin has been correlated with human and animal bonding circumstances, such as mate-bonding, mother–child bonding, and general social bonding. Therefore, the release of oxytocin while listening to music has important implications for individual-to-individual bonding, peer-group bonding, and the development of a social identity in many settings, such as courting lovers, religious groups, college students and alumni groups, business groups, and military organizations.

2.2.1 Musical Structure and Music Theory, Neurobiology of Musical Listening

Music is composed of individual notes, with each note corresponding to a different pitch or frequency (Surmani et al. 2004). In general, the higher the perceived pitch of a given note, the higher will be the frequency of the associated vibration; similarly, the lower the perceived pitch of a note, the lower the frequency. There are seven basic notes, including A, B, C, D, E, F, and G, along with their corresponding sharps and flats. These notes can be arranged into various chords and scales (e.g., major, minor, pentatonic) built around each of the root notes and form the backbone of the structure of music. In Western music, there are 12 different notes that represent the

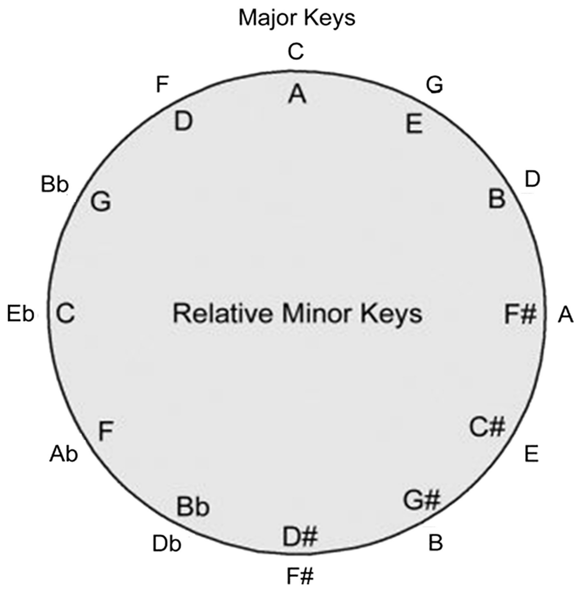

Fig. 2.5 The *Circle of fifths*. The diagram demonstrates the relationships between musical keys. The major keys are shown on the *outside of the circle*, while the minor keys are shown on the *inside of the circle*. As one progresses along the *circle of fifths* from the major key of *C*, there is a systematic change in the number of sharps or flats associated with each key. Adapted from Hetland (2000), with permission from the author

roots of the major and minor keys, as shown in the Circle of Fifths: C, G, D, A, E, B, F#, Db, Ab, Eb, Bb, and F (see Fig. 2.5). The circle of fifths is a visual representation of the 12 tones of the chromatic scale, along with their corresponding key signatures and associated major and minor keys. The circle is very helpful for musicians and composers while composing and harmonizing melodies, building chords, and moving to different keys within a composition (Surmani et al. 2004).

Once a musical composition is complete, whether the genre is rock, classical, jazz, or pop, it will have numerous features that can be broken down into basic components that are all processed simultaneously in the brain during the listening process. These features of music include basic pitch, pitch contour, melody, harmony, timbre, form, dynamics, duration, articulation, temporal structure (rhythm, meter, beat, tempo), consonance and dissonance, loudness, and emotional responses. As mentioned above, *pitch* is the perceived sensation of the frequency of a given note in a piece of music, with different notes being relatively higher or lower in pitch to one another. Most people have relative pitch, with the ability to perceive basic differences in pitch interval or frequency (i.e., higher or lower) between two notes or a series of notes. Perfect or absolute pitch is the ability to identify, after hearing a random musical note without comparison with other notes, its exact pitch (e.g., middle C). Perfect pitch is uncommon, with an estimated incidence of 1 in 10,000 individuals (Ross et al. 2005). The difference in frequency between two pitches is called an interval, with the common intervals being thirds and fifths, from the root pitch or note. It is common in Western music to form larger pitch structures called chords, which contain more than two pitches. The most basic type of chords begin with the root pitch or root note in the lowest position and then add in a note that is a third above the root, followed by a note that is a fifth above the root (or another third above the second note in the chord; e.g., C major chord: **C**-E-G). *Pitch contour* refers to the relative change in pitch over time of a primary sequence of notes in a piece of music (i.e., the "ups" and "downs" in the song).

The pitch contour (or "envelope" of pitches around the core notes of the music) can vary widely between songs and types of music (e.g., a simple folk song vs. a robust classical composition). The *melody* of a piece of music consists of the linear succession of pitches or notes (i.e., the "horizontal" aspect of music) that the listener perceives as a single musical phrase or entity that is the centerpiece of the song. Melodies often consist of one or more musical phrases or motifs and are typically repeated throughout the composition in various forms. The core of a given melody is usually created with the use of chord progressions, scales, or modes. In Western classical music, an initial melody or theme is usually introduced and then followed by variations on the primary melody. In jazz, the "lead" or main melody is used as a starting point to begin the song, followed by improvisation into secondary or counterpoint melodies. In rock, folk, and pop music, there are usually two related melodies (i.e., verse and chorus) that are used throughout the song, with possible variations in the phrasing and lyrics within each component. *Harmony* within a musical piece refers to the use of simultaneous pitches or notes that can be provided by the use of chords, multiple instruments, multiple voices, or a mixture thereof.

In contrast to melody, harmony is considered the "vertical" aspect of music and involves chords, chord construction, and chord progressions. In Western music, most harmonies are tertian, with the pitch intervals based on thirds (e.g., root, third, fifth, seventh), giving a consonant or pleasing sound. In some forms of music (e.g., jazz), the harmonic structures may be different, using chords and chord progressions that have more dissonant qualities. The temporal structure of a musical piece has several components, including the *rhythm*, *meter*, *beat*, and *tempo*. The *rhythm* of a song consists of the arrangement or pattern of sounds (i.e., pitches, notes) and silences over time and is often consistent throughout a given melody. In Western music, the rhythm of a song is usually arranged with respect to a time signature or *meter*, in which a measure is defined as having a certain number of beats (e.g., 2/4 time, 4/4 time). The *beat* of the music is the underlying periodic pulse or tactus of a composition (e.g., the beat of the bass drum in rock music) that induces listeners to entrain as they tap their feet with the song. The *tempo* of a song is the speed or frequency of the beat and is usually measured in "beats per minute" or bpm. The tempo can differ significantly between various styles of music, ranging from 40 bpm to over 200 bpm. *Timbre*, also known as tone color or tone quality, refers to the unique characteristics of a given note or sound and allows us to perceive the differences between different voices, as well as between various musical instruments, such as string instruments, wind instruments, horns, and percussion instruments. For example, if an electric guitar, piano, and French horn are all playing the same note (e.g., middle C) at the same loudness, they are easily differentiated from each other based on characteristics of timbre and sound quality. Some of the terms used to analyze the differences in timbre between different musical instruments include harmonics, spectral envelope, time envelope, brightness, warmth, and tonal character.

Harmonics refer to the frequencies of sound that are produced by a given instrument that may be above or below the fundamental frequency (e.g., middle C) being played, and in many cases will be both. The spectral and time envelope of a given instrument refers to several qualities of its sound, such as attack time, attack characteristics, decay, sustain, and release (i.e., the ADSR envelope). The envelope is the overall amplitude structure of a sound, which is unique between different voices and different instruments. Musical *dynamics* refers to the softness or loudness of a note or musical phrase (e.g., pianissimo, fortissimo), while musical *articulation* describes the specific techniques used to execute or play the notes or phrases (e.g., staccato, legato). Musical *consonance* and *dissonance* generally refer to the quality of chord and harmonic structures, and whether they are complementary and pleasing to the ear or not. Consonant chords and harmonies have pitch intervals that are complementary (e.g., octaves, thirds, fifths) and increase each other's resonance, and are generally considered to be pleasant to the listener. In contrast, dissonant chords and harmonics have intervals that are considered "unstable," with an aural need (i.e., musical tension) to resolve to a more stable musical consonance. Dissonance is quite variable between cultures and, even within Western music, between musical styles (e.g., jazz vs. rock). Although dissonance may be associated with "unpleasant" sounding chords and harmonies, it is able to add complexity, richness, and nuance to many melodies, especially when the dissonance is allowed to resolve toward consonance during the conclusion of the song.

Music is perceived in the same manner as any other sound in our environment and must be processed via the tympanic membrane, middle ear ossicles, cochlea, VIIIth cranial nerve, ascending auditory pathways, and primary auditory cortex (see Fig. 2.6) (Parent 1996; Ryland 2009). Music will produce a complex mixed

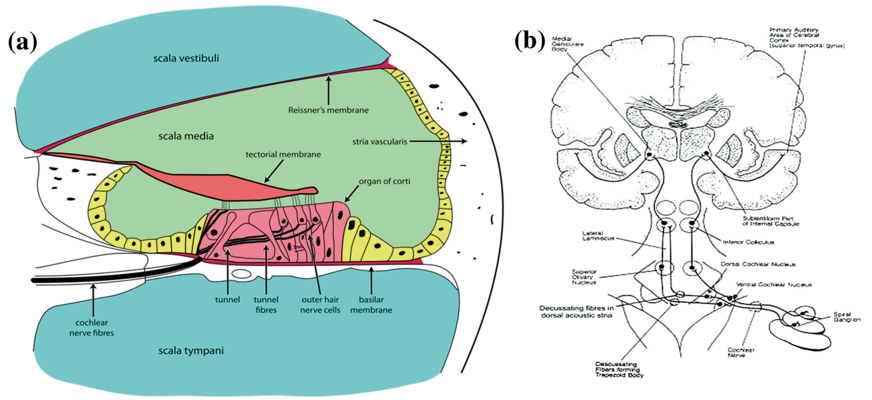

Fig. 2.6 **a** Cross section of the cochlea, demonstrating the organ of corti and tectorial membrane within the scala media. Adapted from Wikipedia. **b** The auditory pathway begins in the cochlea and then travels via cranial nerve VIII (i.e., cochlear nerve) to the brainstem, where it passes through relay nuclei including the ventral and dorsal cochlear nuclei, superior olivary nuclei, inferior colliculi, and medial geniculate bodies, before terminating in the primary auditory cortex, which is located in the superior temporal gyrus. See text in Sect. 2.1 for further details

frequency sound wave that will interact with the tympanic membrane of both ears, thereby transmitting an acoustic signal to the ossicles of the middle ear. The ossicles of the middle ear consist of the malleus, incus, and stapes and are responsible for transferring the acoustic signal, through the oval window, into a hydraulic signal within the fluid of the inner ear and cochlea. Since the tympanic membrane has a surface area approximately 17× greater than the oval window, the ossicles allow for the sound pressure of the acoustic signal to be concentrated, with a pressure gain of at least 20× as it is transmitted to the cochlea. This gain is a form of impedance matching, since it takes more energy and pressure to move pressure waves through a liquid media than through air.

The cochlea consists of a fluid-filled coil tube of two and a half turns, and functions as an auditory transducer. Internally, the cochlea is partitioned into the scala vestibuli, scala tympani, and scala media (or cochlear duct) by the basilar and vestibular membranes. Sound energy is transmitted to the perilymph within the scala vestibuli through the round window via the foot plate of the stapes. The auditory transducing instrument is the *organ of Corti*, which lies within the scala media (surrounded by endolymph) on top of the basilar membrane, and consists of one row of inner hair cells and three rows of outer hair cells. The inner hair cells provide the main neural output of the cochlea, while the outer hair cells function as a preamplifier, receiving input from the brain that modifies the activity of the organ of Corti.

Overhanging the organ of Corti is the tectorial membrane, which is in contact with the hair cells. Sound energy transmitted to the perilymph through the oval window will set up traveling fluid waves within the scala vestibuli that correspond to the same frequencies as the acoustic signal. The fluid waves propogate from the base of the cochlea toward the apex, where the scala tympani and scala vestibuli merge (i.e., helicotrema). Because the vestibular membrane is so thin and delicate, the scala vestibuli and scala media function as a singular hydraulic unit as sound waves are propogated down the cochlea. The fluid waves within the endolymph of the scala media peak at a specific distance from the oval window, depending on their inherent frequencies, thereby causing vibrations and displacing the basilar membrane. Movement of the basilar membrane causes vibrations and movement of the overlying organ of Corti, with stimulation of the hair cells in that region of the cochlea. The organ of Corti functions as an audio frequency analyzer and is tonotopically organized, so that the highest frequency sounds maximally stimulate hair cells in the most basal portion of the cochlea, where the basilar membrane is narrow. Tones with the lowest frequencies maximally stimulate hair cells in the apical regions of the cochlea. Movement of the outer hair cells further amplifies the vibrations within the organ of Corti, resulting in stimulation of the inner hair cells. Once the inner hair cells have been stimulated, they depolarize via an influx of $K+$ through channels near the tip region, resulting in activation of dendrites from bipolar afferent nerves located within the spiral ganglion (i.e., cochlear portion of the vestibulocochlear nerve; CN VIII). Most cells of the spiral ganglion innervate a section of the basilar membrane that is only a single hair cell in width, corresponding to the frequency it is designed to respond to.

The cochlear nerve, which consists of the central processes of the cells in the spiral ganglion, travels medially from the inner ear and enters the brainstem at the junction of the medulla and pons (Parent 1996; Ryland 2009). As the nerve enters the brainstem, it bifurcates and makes synaptic connections with neurons in the dorsal and ventral cochlear nuclei. Both cochlear nuclei are tonotopically organized, but have different cellular components and cytoarchitecture. Neurons responding to higher frequencies are more dorsal, while those responding to lower frequencies are ventral.

There are three efferent projections from the cochlear nuclei: the dorsal, intermediate, and ventral acoustic striae. The dorsal acoustic stria originates from the dorsal cochlear nucleus and crosses over to the contralateral side, to join the fibers of the lateral lemniscus. The intermediate acoustic stria originates from the ventral cochlear nucleus and has a course similar to the dorsal stria, crossing over to join the lateral lemniscus. The ventral acoustic stria passes medially to terminate in the ipsilateral and contralateral nuclei of the trapezoid body and superior olivary nuclei, which then project fibers into the ipsilateral and contralateral lateral lemniscus. The fibers of the lateral lemniscus travel rostrally through the brainstem, mainly terminating in the nucleus of the inferior colliculus and the medial geniculate nucleus, along with a few fibers that terminate in the nearby nuclei of the lateral lemniscus. Some of the fibers of the lateral lemniscus bypass the inferior colliculus and project directly to the medial geniculate as the central acoustic tract. A tonotopic organizational structure is maintained within the nuclei of the inferior colliculus and medial geniculate body. Efferents from the nucleus of the inferior colliculus project rostrally through the brachium of the inferior colliculus to terminate in the medial geniculate nucleus.

The medial geniculate bodies are special sensory nuclei of the thalamus and are the final relay station of the hearing pathway. The efferent projections from the medial geniculate bodies form the auditory radiations (i.e., geniculocortical fibers), which travel to the ipsilateral temporal lobes, into the anterior transverse temporal gyri (i.e., gyrus of Heschl; Brodmann area 41), which is considered the location of the primary auditory cortex. The gyri of Heschl (HG) are located on the dorsal surface of the superior temporal convolutions and are partly buried in the lateral fissure. Cytoarchitectonically defined primary auditory cortex is located in the medial portion of HG, running anterolaterally in the plane. Lateral to the primary auditory cortex in HG are secondary auditory cortical regions. Behind HG lies the planum temporale (PT), which is considered to be an auditory association area. Basic processing of sound occurs at lower levels of the auditory pathway, so that the primary auditory cortex is not required for crude discrimination of sound frequency and intensity. However, it is necessary for processing the temporal patterns of sound and for determining sound direction, as well as for allowing higher level processing of complex sounds (e.g., music) in other functionally related brain regions (Metherate et al. 2005; Nelken 2008).

2.2.2 Neuroanatomy of Musical Processing and the Brains of Non-musicians

Early theories about the neurological aspects of musical processing, in the 1960s through 1980s, involved the concept of hemispheric specialization, and the idea that the left and right hemispheres had very distinct functions, some of which were very compartmentalized, such as language in the left hemisphere and emotional responsivity in the right hemisphere (Walker 1980; Kyle 1988). Based on this framework, musical abilities and music processing were thought to be predominantly a right-hemispheric function for many years (Berman 1981). It was not until more detailed studies of patients with brain lesions (e.g., strokes, gunshot wounds), degenerative diseases (e.g., Alzheimer's Disease, frontotemporal dementia), and congenital and acquired amusia, along with study of normal subjects using functional imaging techniques [i.e., functional MRI, magnetoencephalography (MEG), PET], that it became apparent that the neural analysis of music was more diffuse and bi-hemispheric (Peretz and Coltheart 2003; Peretz and Zatorre 2005; Griffiths 2001; Limb 2006). Many experts in the field, including Peretz, Griffiths, and Limb, are now suggesting that musical perception and analysis by the brain is a more modular process that can be broken down into smaller components, especially when using modern functional imaging techniques. This has led to the proposal of a cognitive model of musical processing by Peretz and colleagues (see Fig. 2.7), that is a preliminary attempt to demonstrate how musical acoustic inputs are analyzed and compartmentalized into distinct neuropsychological components (Peretz and Coltheart 2003; Stewart et al. 2006). The core of the model contains compartments for pitch analysis and temporal analysis, along with

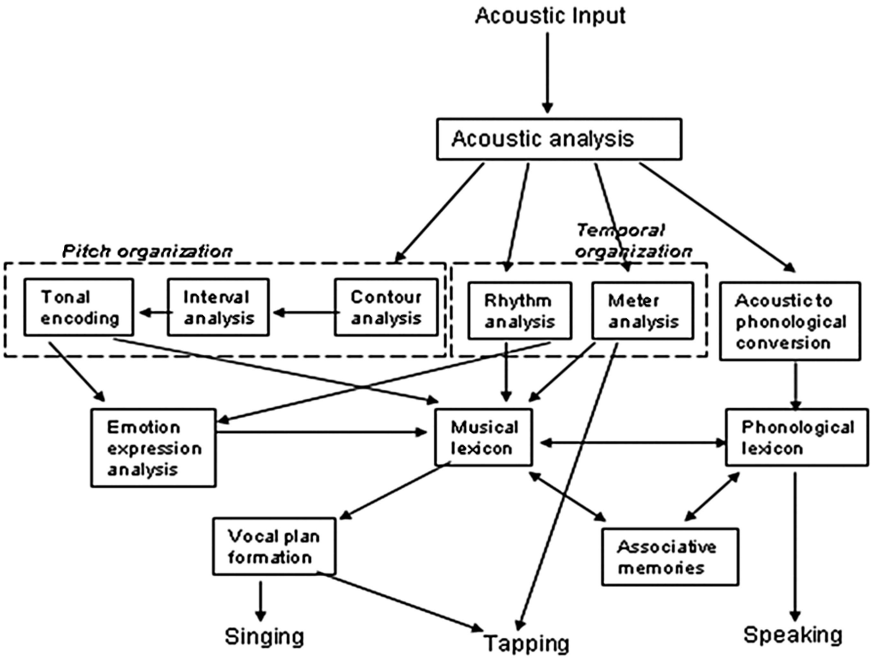

Fig. 2.7 Model of music processing as proposed by Peretz and colleagues. The musical acoustic signal is initially analyzed in parallel in the "pitch organization" and "temporal organization" compartments, followed by further processing for emotional expression, comparisons with the musical lexicon and phonological lexicon, and evaluations for associative memories. Adapted from Herdener et al. (2014), Hoppe (1988)

other aspects of musical processing. However, the model is somewhat simplistic and does not take into account many other aspects of the musical acoustic signal and music processing (e.g., timbre, harmony, beat) that have been studied in patients and normal subjects. In the following sections, we will review in detail the different structural components of music (as discussed in Sect. 2.1), and how these components are analyzed and processed within the primary and secondary auditory cortices, and related music-specific neural networks.

The most extensively studied aspects of musical structure have involved pitch perception, pitch contour, and melody (Griffiths 2001; Limb 2006; Stewart et al. 2006; Tramo et al. 2005). Although not all of the results have been consistent, the majority of studies varying pitch, pitch strength, and pitch structure have demonstrated activation in the secondary cortex in lateral HG, instead of primary auditory cortex (Gutschalk et al. 2002; Patterson et al. 2002; Penagos et al. 2004; Griffiths 2003). In addition, the report from Gutschalk et al. (2002) also noted that a region just posterior to the PT was very sensitive to the sound level and loudness of a given pitch stimulus, as opposed to its absolute pitch or regularity (Gutschalk et al. 2002). These studies and others have suggested the possibility of a "pitch center" in the lateral HG region, responsible for primary pitch processing of complex auditory inputs (Stewart et al. 2006; Griffiths 2003; Bendor and Wang 2006; Puschmann et al. 2010). For example, one recent study using fMRI techniques had subjects listen to pure tones in noise and dichotic pitch sequences and demonstrated pitch-related neural activation in the lateral end of HG in both hemispheres (Puschmann et al. 2010).

These findings and conclusions have been supported by neuronal recording studies in primates, which also suggest the existence of a "pitch center" within the secondary auditory cortex lateral to HG (Bendor and Wang 2005). Other work in primates, cats, and similar animals suggest that frequency-sensitive neurons in the primary auditory cortex may also contribute to basic pitch perception; for example, the ability to aid in fine-grained pitch discrimination or detect the direction of pitch change (i.e., higher or lower) (Tramo et al. 2005). A more recent study in non-musicians using fMRI techniques and multivariate pattern analysis examined pitch contour discrimination using variable ascending and descending melodic sequences (Lee et al. 2011). They also identified the right superior temporal sulcus region as being highly activated in this setting. In addition, there was also significant activation within the left inferior parietal lobule and the anterior cingulate cortex. Although the data presented above seem fairly consistent, a new report by Barker and colleagues using fMRI techniques challenge the concept of a "pitch center" in the lateral HG and state it might be artifactual, based on previous studies using the wrong kind of auditory stimuli, which contain slowly varying spectrotemporal modulations unrelated to pitch (Barker et al. 2012). Further research into the functional anatomy and neurobiology of primary pitch processing will be necessary before any final conclusions can be drawn.

When the brain is processing musical auditory inputs that involve more complex pitch structures such as melodies, chords, and harmonies, the analysis must be able to dissect the global structure of the auditory signal (i.e., pitch contour; the pattern of "ups and downs"), as well as the more local level of the precise pitch intervals that comprise the contour (Griffiths 2001; Limb 2006; Stewart et al. 2006; Tramo et al. 2005). Early evidence from neuroanatomically based lesion studies in patients (e.g., post-stroke, frontotemporal degeneration, epilepsy surgery) suggested that processing of the global structure and pitch contour would occur in the right posterior superior temporal cortex, in advance of local processing within the left posterior superior temporal cortex (Peretz 1990; Liégeois-Chauvel et al. 1998). These analyses would be hierarchically linked, such that the pitch contour would have to be analyzed first, to provide an acoustic context for the signal, followed by processing of the local structure and fine detail to place within the global framework.

In a study to evaluate this process in normal healthy subjects, Stewart and coworkers used fMRI, while participants listened to consecutive pitch sequences and performed a same/different one-back comparison task (Stewart et al. 2008). When sequences were different, they either preserved (locally different) or violated (globally different) the contour of the sequence preceding them. The results showed that during global pitch contour processing, there was activation of the left PT and posterior superior temporal sulcus (pSTS) region. In contrast, during local pitch processing, there was bilateral activation of the PT and pSTS regions (see Fig. 2.8). Therefore, the brain seems to be able to analyze pitch contour and the

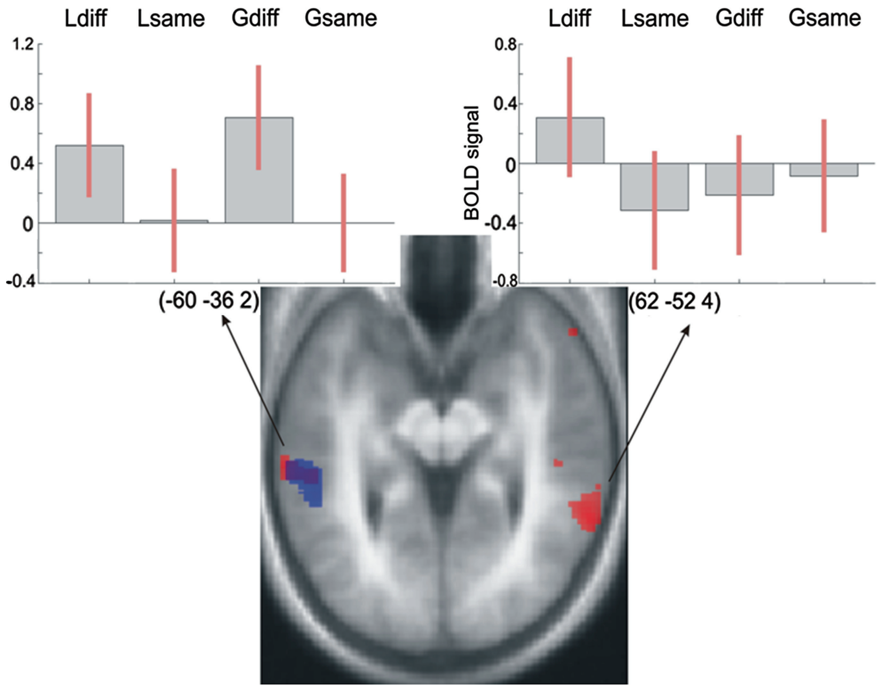

Fig. 2.8 fMRI results in a non-musician subject during global pitch contour processing and local pitch interval processing. During the global pitch contour processing, there was activation of the left PT and posterior superior temporal sulcus (pSTS) region (*seen in blue*). In contrast, during local pitch interval processing, there was bilateral activation of the PT and pSTS regions (*seen in red*). See text in Sect. 2.2 for further details. Adapted from Kunej and Turk (2000), with permission from the senior author

global structure of a pitch sequence while only using the left PT and pSTS, while for local pitch processing, more neural resources are required so that the bilateral PT and pSTS regions require activation. Although these results are not entirely consistent with the older, anatomically based studies in neurologically impaired patients, they are still supportive of the hierarchical model that proposes initial global processing of pitch contour, followed by processing of more detailed local pitch structure, within the PT and pSTS regions of the brain. It is likely that the neural pitch processing apparatus noted above is not specific to music, but is also critical for analysis of the pitch changes necessary for language and the linguistic interpretation of prosody.

Numerous other studies have been performed to evaluate different aspects of musical auditory signal processing, such as pitch, melody, timbre, and time structure (Griffiths 2001; Limb 2006; Stewart et al. 2006; Tramo et al. 2005). Several studies have used fMRI techniques to analyze neural processing of basic pitch and melody, using different auditory stimuli (Gutschalk et al. 2002; Puschmann et al. 2010). In one report, pure tones in noise or dichotic pitch sequences, which either contained a fixed pitch or a melody, were used in normal subjects (Puschmann et al. 2010). They noted activation of the lateral end of HG in both hemispheres during processing of dichotic pitch sequences. When the dichotic pitch stimuli contained a melody, the activation was more evident in the PT and the planum polare (anterior portion of the superior surface of the superior temporal gyrus), but not in primary auditory cortical regions. In a similar study, the auditory stimuli were spectrally matched sounds that produced no pitch, fixed pitch, or a melody (Patterson et al. 2002).

All of the different auditory stimuli were noted to activate HG and PT, although sounds with pitch produced more activation in the lateral half of HG in comparison with sounds without pitch. When the stimulus contained a melody, neural activation beyond HG and PT was noted, more laterally within the superior temporal gyrus and planum polare. The authors concluded that there was a hierarchy of pitch processing in the brain, such that as the auditory stimuli become more complex (e.g., basic pitch sequences vs. melody), the center of activation moves anteriorly and laterally away from primary auditory cortex. Another fMRI study scanned volunteers as they were listening to pure-tone melodic-like sequences, while the pitch distances between consecutive tones were varied in a parametric fashion (Hyde et al. 2008). They noted that the right PT was linearly responsive to increasing pitch distance, even when the change in pitch was very subtle. In contrast, the degree of activation in the left PT was relatively constant as a function of pitch distance, except at the largest pitch change. This study supports the model of the right secondary auditory cortex being more important for the processing of fine pitch resolution. In a study using PET techniques, designed to evaluate the ability of subjects to remember and compare melodic pitch sequences at different points, processing of pure melodies (versus noise bursts) resulted in activation in the right superior temporal and right occipital cortices (Zatorre et al. 1994). When subjects were required to remember and compare the first two notes of a pair of melodic pitch sequences, there was activation within the right inferior frontal opercular region. In the most demanding task, subjects had to compare the pitch of the first and last notes of a pair of melodic sequences. In this task, there was further activation of brain regions, including the right frontal and right temporal lobes, as well as within the parietal and insular cortical regions.

In Western styles of music, the listener usually has a certain degree of expectation about the musical notes that will fit properly within a specific musical reference, in relation to the musical key, melody, harmony, and chord structure (Peretz and Zatorre 2005; Griffiths 2001; Limb 2006). This kind of expectant relational pitch framework can be considered "musical syntax" and is analogous to the syntactical rules necessary for analysis of language. Violations of these musical expectancies are considered violations of musical syntax, in which the listener is able to pick out a note or chord that does not fit within the given key (e.g., melody in C major, but C# is used instead of C natural).

Several studies have now suggested that neural processing of musical syntax occurs in the frontal lobes, within or near Broca's area, which is critical for the syntactic processing of language (Maess et al. 2001; Janata et al. 2002; Koelsch and Siebel 2005). In a study using MEG, Maess et al. (2001) presented a series of chords to non-musician listeners, some of which had out-of-key notes but still maintained the proper major or minor chord structure (i.e., Neapolitan chords). The Neapolitan chords resulted in the presence of an early effect called the magnetic equivalent of the early anterior negativity (mERAN), since it was analogous to EEG studies which show an ERAN in response to musical syntactic violations. The source of the mERAN was localized to Broca's area and its right hemisphere homolog. Other studies using fMRI suggest that more mesiofrontal regions are important for monitoring the key of a given piece of music, as well as the history of keys being processed in the melody (Janata et al. 2002; Koelsch and Siebel 2005). Overall, these kinds of studies support the notion of musical syntax and imply that the neural processing of musical syntax involves Broca's area and nearby regions of the frontal lobes, which have traditionally been thought to only be important for language.

As mentioned above, timbre is the quality of a sound that allows the listener to discriminate between different sound sources and different musical instruments (Surmani et al. 2004). Differences in spectral envelope, harmonics, attack, and other sound qualities account for the timbre of various instruments. An early study using PET evaluated the structural components of musical perception, including timbre, during a series of musical tasks (Platel et al. 1997). For the timbre task, two synthesized timbres in the sound spectrum of an oboe were used and presented in various patterns. During the timbre tasks, there was predominant activation of the right hemisphere, mainly within the superior frontal gyrus and middle frontal gyrus. In contrast, more recent studies using fMRI suggest that the temporal lobes are the primary brain regions involved in the neural processing of timbre (Warren et al. 2005; Menon et al. 2002; Samson 2003; Halpern et al. 2004). In a general study of the neural processing of the spectral envelope of different sounds, changing either the pitch or the spectral envelope of harmonic sounds activated the HG and adjacent regions of the superior temporal lobes bilaterally (Warren et al. 2005).

Changing the spectral envelope of continuously alternating noise and harmonic sounds resulted in additional right-lateralized activation in the superior temporal sulcus. Using musical sound stimuli in which several aspects of timbre were altered simultaneously, Menon and co-workers noted significant activation in posterior HG and superior temporal sulcus, with some extension into the circular insular sulcus (Menon et al. 2002). No significant difference was present between right and left hemispheric activation. However, there was a more posterior predilection for activation in the left temporal lobe in comparison with the right temporal lobe, suggesting a functional asymmetry. In a study of perceived versus imagined timbre, subjects had to make comparative judgments of timbral characteristics of musical instrument sounds (Halpern et al. 2004). During the perceptual timbre tasks, there was activation of primary and secondary auditory cortices, with a mild right-sided asymmetry. During the timbre imagery task, activation of secondary auditory cortical regions was noted, with significant overlap with the perceptual task findings. Overall, the available studies would suggest that brain processing of musical timbre is performed within a neural network that extends along the superior temporal gyrus, including both anterior and posterior regions, with a possible mild right-sided predominance (Samson 2003). The frontal lobes may also play a minor role in neural processing of musical timbre.

The neural processing of the temporal organization of music (i.e., rhythm, meter, beat, tempo) has not been as clearly delineated as the processing of pitch perception Herholz and Zatorre (2012); Herholz et al. (2012); Hetland (2000). Earlier studies investigated the temporal aspects of music by having subjects respond to and reproduce progressively complex rhythms (Penhune et al. 1998; Griffiths et al. 1998; Sakai et al. 1999). In a PET study, activation was noted in the lateral cerebellar cortex and cerebellar vermis during the performance of timed motor responses, especially when the stimulus to be reproduced was complex (Penhune et al. 1998). The basal ganglia structures were also activated during the task, but to a lesser degree. In a fMRI study, Griffiths and colleagues used a "delay-and-add" noise strategy, which is supposed to activate all frequencies uniformly, similar to noise, but can also produce strong pitch perceptions and melodies (Griffiths et al. 1998). The sound stimulus also had temporal regularity which could be systematically altered. They noted that the primary auditory cortex was activated in proportion to the regularity of the stimulus. When the sound stimulus contained a melody as well as temporal regularity, activation was also present in areas outside of the primary auditory cortex region (i.e., more posteriorly into secondary auditory cortex).

Another fMRI-based study attempted to compare auditory stimuli that varied based on metrical and non-metrical representations of rhythms formed with small integer and non-integer ratios (Sakai et al. 1999). During the integer-based auditory tasks, which is more representative of music, there was increased activity present in the anterior lobe of the cerebellum. Several recent studies using fMRI corroborate the involvement of the cerebellum and related pathways in the neural processing of temporal structure and auditory timing (Xu et al. 2006; Teki et al. 2011). During the perception and motor performance of temporal sequences, fMRI was used to dissociate the perceptual from the motor aspects of timing (Xu et al. 2006). The results demonstrated the activation of multiple areas within the cerebellar cortex during the perception tasks and the motor performance tasks. In addition, it was noted that the inferior olive was activated only when the subjects perceived the temporal sequences, without any associated motor activity. This suggests a primary role for the olivo-cerebellar climbing fiber system in the encoding of temporal information, independent of motor behavior. In a similar study, subjects were asked to judge the difference in duration of two successive time intervals as a function of the preceding context of an irregular series of clicks or a regular series of clicks (Teki et al. 2011). During the absolute, duration-based timing tasks, there was activation of the olivo-cerebellar network, including the inferior olive, vermis, and deep cerebellar nuclei (i.e., dentate nucleus). In contrast, during the relative, beat-based timing tasks, there was activation of a striato-thalamo-cortical network, including the putamen, caudate nucleus, thalamus, supplementary motor area, premotor cortex, and dorsolateral prefrontal cortex. Therefore, these results suggest two distinct neural timing mechanisms and subsystems: one involving the olivo-cerebellar pathways that acts as a precision clock to mediate duration-based timing, and another that involves a striato-thalamo-cortical network that mediates relative, beat-based timing. A recent fMRI study had subjects find and tap to the beat of rhythms that were varied from metrically simple to metrically complex (i.e., from a strong to a weak beat) (Kung et al. 2013). The beat finding and beat tapping activity activated overlapping brain regions that included the superior temporal gyrus, premotor cortex, and ventrolateral prefrontal cortex (VLPFC). Beat tapping activity in the superior temporal gyrus and VLPFC was correlated with both perception and performance, suggesting that they were important for retrieving, selecting, and maintaining the musical beat.

Basal ganglia activation was noted as well, but was similar in all conditions and did not correlate with either perception or production of the beat. Not all of the studies have been consistent, since another report using fMRI to monitor subjects responding to music that was either intact or scrambled suggested activation in the temporal lobes (Fedorenko et al. 2012). All subjects listened to passages of intact music, scrambled music, pitch scrambled music, and rhythm scrambled music, as well as linguistic tasks. Intact music induced more potent activation in the brain than scrambled music, involving the anterior STG bilaterally, posterior superior and middle temporal gyri bilaterally, premotor regions, and the supplementary motor areas. When the pitch structure was scrambled or the rhythmic structure was scrambled, similar but less significant activation was noted bilaterally in the temporal lobes. Linguistic tasks did not activate these regions of the brain. Similarly, a study by Limb et al. (2006) used fMRI to study passive rhythm perception in non-musicians and musicians. Subjects were required to listen to regular and random rhythmic patterns, without any verbal or motoric responses. A pattern of activation was noted in a network responsible for rhythm perception in the bilateral superior temporal regions, left inferior parietal lobule, and the right frontal operculum, in both non-musicians and musicians. Some laterality was noted in the musicians, which will be described in the next section.

Since music is so ubiquitous in most modern societies, the average teenager or adult will have a vast repertoire of songs and musical passages that are familiar and can be easily recognized or imagined in their mind. The neural representations of these songs, melodies, and musical phrases are stored in a music-specific memory system that has been termed the "musical lexicon" by Peretz and colleagues (2003, 2005, 2006). Neuroscientists have attempted to localize the neural structures responsible for recognizing songs and melodies for many years, initially in patients with brain damage (Peretz 2006; Peretz and Zatorre 2005; Griffiths 2001). The brain damage literature (e.g., stroke, Alzheimer's, frontotemporal degeneration) suggests that deficits in the perception and recognition of familiar songs and melodies can arise with injuries involving the right or left anterior STG and insula, while the more specific loss of the ability to recognize familiar tunes seems to involve damage to the right insula (Griffiths 2001; Ayotte et al. 2000).

Early studies of intact subjects using PET techniques, scanned while each was engaged in a task of imagining the continuation of a tune after hearing a short series of notes (Halpern and Zatorre 1999). There was activation primarily on the right side in the frontal and superior temporal regions, plus the supplementary motor area. During the retrieval of real tunes, there was activation mainly in the right frontal areas and right superior temporal gyrus. Similar results have been described in a series of fMRI studies using intact subjects (Rauschecker 2005; Janata 2005; Peretz et al. 2009; Schulze et al. 2011; Herholz et al. 2012). In one study, subjects were asked to anticipate the continuation of music from very familiar songs and imagine the appropriate sequence of notes versus actually hearing the complete musical passage (Rauschecker 2005). Activation was noted in the right anterior superior temporal cortex, right inferior frontal cortex and anterior insula, left anterior prefrontal cortex, lateral cerebellum, and the anterior cingulate. In a similar study, Herholz et al. (2012) asked subjects to view the lyrics of familiar tunes, while listening to the song or imaging the music, during fMRI evaluation.

There was significant overlap during melody perception and imagery, including activation of the secondary auditory cortices. During the imagery task, an extended network was activated, including prefrontal cortex, supplementary motor areas, intra-parietal sulcus, and the cerebellum. In addition, during the musical imagery task, there was increased functional connectivity of the anterior right temporal cortex with the frontal areas, suggesting these regions form an imagery-related network. Using a different experimental paradigm with fMRI, Peretz and colleagues studied non-musician subjects, while they listened to familiar musical themes, unfamiliar music, or random tones. All of the stimuli were synthesized and played with the sound of a piano. While listening to familiar musical passages, there was focal activation in the right superior temporal sulcus region. In addition, these auditory memories were tightly coupled with action (e.g., singing), by demonstrating left-sided activation of the PT, supplementary motor areas, and inferior frontal gyrus. In a study by Schulze and co-workers, fMRI was used to examine verbal and tonal working memory (WM) in a cohort of non-musicians and musicians (Schulze et al. 2011). It was theorized that non-musicians would be trained in speech and verbal domains, but not in music, while musicians would be trained in both domains. It was noted that core structures of WM were involved in both tonal and verbal WM in non-musicians and musicians, including Broca's area, premotor cortex, presupplementary motor area and supplementary motor area, left insular cortex, and inferior parietal lobe. In musicians, additional activation was noted in the right insular cortex during verbal WM tasks, as well as in the right globus pallidus, right caudate nucleus, and left cerebellum during tonal WM tasks. These results suggest two different WM systems in musicians: one for verbal and phonological information and another for melodic and tonal information.

The ability of music to evoke and inspire specific emotions is well recognized, and one of the most powerful reasons that music remains so pervasive in cultures throughout the world and for so many individuals (Peretz and Zatorre 2005; Griffiths 2001; Limb 2006). As mentioned above in Sect. 2.2, many investigators now think that music, and in particular song-like vocalization, was a proto-language that predated modern speech and language during the evolution of Homo sapiens (Peretz 2006; Masataka 2009). As part of that process, some vocalizations became less emotional and more semantic, evolving into language, while the other pathway preserved the emotional connections along with semantic ambiguity and evolved into music (Perlovsky 2010). Lesion-based studies investigating the loss of enjoyment or lack of emotional response to music in patients with various disease processes (e.g., stroke, Alzheimer's disease, neurodegenerative diseases, surgical resection) have most consistently noted damage involving the left or right medial temporal lobe, amygdala, and insula (Griffiths 2001; Omar et al. 2011). For example, in a recent study of patients with frontotemporal dementia, lack of emotional responses to music was correlated with a loss of gray matter in a network that included the insula, orbitofrontal cortex, anterior and posterior temporal cortices, amygdala, and subcortical mesolimbic connections (Omar et al. 2011).

It is now becoming apparent from functional studies (i.e., PET, fMRI) in normal subjects that the neural basis of music-evoked emotions involves connectivity between the networks that mediate musical perception and more primitive mesiolimbic structures (Griffiths 2001; Blood et al. 1999; Blood and Zatorre 2001; Brown et al. 2004; Menon and Levitin 2005; Koelsch 2010; Salimpoor et al. 2011). Early studies by Blood and colleagues used PET scans and measurements of alterations in cerebral blood flow that were related to affective responses to music (Blood et al. 1999; Blood and Zatorre 2001). In the first study, they had subjects listen to six versions of a novel musical passage while varying the degree of melodic consonance and dissonance (Blood et al. 1999). Blood flow alterations were noted in the right parahippocampal gyrus, right precuneus, bilateral orbitofrontal regions, medial subcallosal cingulate, and the right frontal polar regions. The amount of blood flow alteration correlated with the degree of perceived pleasantness or unpleasantness of the musical passages. Another study used PET to evaluate subjects while listening to intensely pleasurable music that could cause "chills" or send "shivers down the spine" (Blood and Zatorre 2001). As the intensity of the chills increased, blood flow alterations were noted in ventral striatum, midbrain, amygdala, orbitofrontal cortex, and ventral medial prefrontal cortex.

All of these brain regions are known to be involved in the neural circuitry mediating reward, motivation, emotion, and arousal and are also known to be active in response to other euphoria-inducing stimuli, including food, sexual activity, and drugs of abuse (Koelsch 2010).

Using a different study paradigm, Brown et al. (2004) used PET to evaluate subjects while listening to unfamiliar but strongly pleasurable instrumental music (Brown et al. 2004). They noted activation in the subcallosal cingulate gyrus, prefrontal anterior cingulate, retrosplenial cortex, hippocampus, anterior insula, and nucleus accumbens. Activation was also noted in the primary and secondary auditory cortices, and temporal polar regions. This was the first study to demonstrate that spontaneous, passive listening to pleasurable music could activate limbic and paralimbic structures and circuitry. In a combined PET and fMRI study, Salimpoor and co-workers analyzed subjects while listening to music well known to cause "peak listening" experiences (Salimpoor et al. 2011). Using [(11)C] raclopride PET, it was shown that dopamine was released into the striatum at the peak of emotional arousal in response to the music. fMRI was then used to plot the time course of dopamine release and showed a functional dissociation: during the anticipation phase, leading up to the peak musical phrases, dopamine release was mainly in the caudate nucleus, while during the peak emotional phase, the nucleus accumbens was more involved. Using fMRI and connectivity analysis in subjects while listening to pleasurable music, Menon and Levitin noted strong activation of the nucleus accumbens, ventral tegmental area, hypothalamus, and insula (Menon and Levitin 2005). Activation was strongly correlated between the nucleus accumbens and ventral tegmentum, as well as between the nucleus accumbens and hypothalamus. Functional connectivity analysis suggested significant ventral tegementum-mediated interaction of the nucleus accumbens with the insula, hypothalamus, and orbitofrontal cortex. In addition, several investigators have examined the role of emotional arousal in the musical listening experience and have found that the degree of emotional arousal correlates strongly with ratings of pleasure, as well as with how memorable a given piece of music is over time (Salimpoor et al. 2009; Eschrich et al. 2008).

2.2.3 *Neuroanatomy of Musical Processing and the Brains of Musicians*

For centuries anatomists, physicians, and neuroscientists have investigated potential differences between the brains of musicians and non-musicians, assuming there must be some quantifiable parameters that correlate with musical expertise and skill (Griffiths 2001; Stewart et al. 2006; Dawson 2011; Bentivoglio 2003; Schlaug 2003). The earliest reports focused on anatomical studies of famous musicians from the nineteenth and early twentieth centuries (e.g., Hans von Bulow, Bernhard Cossmann) (Bentivoglio 2003; Meyer 1977; Auerbach 1906–1913). Some of the anatomical studies concluded that there were differences in the middle and posterior thirds of the superior temporal gyrus, as well as in the supramarginal gyrus, in the brains of these famous musicians. In the modern era, using advanced imaging techniques such as PET, fMRI, volumetric MRI, MRI tractography, functional connectivity analysis, and MEG, the anatomical and functional differences between musicians and non-musicians are becoming more clearly elucidated. Several regions of the brain have been shown to be different in musicians, including the cerebellum, corpus callosum, auditory cortices, motor regions, somatosensory cortex, and superior parietal region (Dawson 2011; Schlaug 2003).

Hutchinson et al. (2003) studied the brains of a group of professional keyboard players and compared them to matched non-musician controls, using volumetric MR imaging (Hutchinson et al. 2003). There was significantly greater absolute and relative cerebellar volume (10.4 % vs. 9.9 %), but not total brain volume, in the male musicians. Relative cerebellar volume was also correlated with the degree of lifelong intensity of practice in the male musicians. In the female group, there was no significant difference in cerebellar volume noted between musicians and non-musicians. Several research groups have documented differences in the size of the corpus callosum between musicians and non-musicians, including an age-related effect (Schlaug et al. 1995; Lee et al. 2003; Ozturk et al. 2002; Steele et al. 2013). Schlaug and colleagues were the first to report this difference, when they studied 30 musicians and compared them to age-, sex-, and handedness-matched controls using in vivo MR morphometry (Schlaug et al. 1995). The anterior half of the mid-sagittal corpus callosum was significantly larger in musicians than non-musicians (mean 371 mm^2 vs. 344 mm^2). This effect was most prominent in the subgroup of musicians who had begun their musical training before the age of 7 ($\leq$7 years = 384 mm^2). A follow-up study from the same group, with an enlarged cohort of musicians ($N = 56$), noted similar findings (Lee et al. 2003). However, in the larger study, the enlargement of the anterior mid-sagittal corpus callosum was most significant in the male musicians, but not in female musicians. The lack of enlargement in the female musicians was felt to be related to a tendency for a more symmetric brain organization in females, as well as a disproportionately high representation of absolute pitch musicians among females. In a similar MRI study of 20 musicians and matched controls, a Turkish group noted significant increases in volume of the anterior and posterior portions of the corpus callosum in the musician cohort (Ozturk et al. 2002). Overall thickness of several regions of the corpus callosum was also greater in the musician group than in controls.

A recent study evaluated the onset of musical training in terms of the white matter organization of the corpus callosum in musicians (Steele et al. 2013). Using diffusion tensor imaging MRI, early- and late-trained musicians matched for years of training and experience were analyzed. In the early-trained group, there was greater connectivity in the posterior midbody/isthmus of the corpus callosum. Fractional anisotropy in this region was related to the age of onset of training and sensorimotor synchronization performance. The authors concluded that onset of musical training before age 7 was associated with changes in white matter connectivity in the brain. The primary and secondary auditory cortices also appear to be anatomically and functionally different in musicians (Dawson 2011; Schlaug

2003). Using MEG techniques Schneider et al. (2002) compared the processing of sinusoidal tones in the auditory cortex of amateur and professional musicians and non-musicians (Schneider et al. 2002). In professional musicians as compared to non-musicians, the activity evoked in primary auditory cortex after stimulus onset was 102 % larger, and the gray matter volume of the anteromedial portion of HG was 130 % larger. Both of these quantitative changes were highly correlated with musical aptitude, as measured by psychometric evaluation. In a different experimental paradigm using scrambled pieces of piano music, musicians and non-musicians appeared to process the auditory signals differently (Matsui et al. 2013). Non-musicians had activation of only the right STG, while musicians had activation of the right and left STG. It was suggested that left STG activation was induced in musicians because the auditory stimuli were musically related. In a study of musicians and non-musicians using fMRI during a passive musical listening task, Ohnishi and co-workers also noted a functional difference in auditory processing (Ohnishi et al. 2001). In musicians, there was predominant activation of the left secondary auditory cortex and the left posterior dorsolateral prefrontal cortex. In contrast, non-musicians had activation of the right secondary auditory cortex for the same task. In addition, there was activation of the bilateral PT in the musician cohort. The degree of activation of the left PT correlated strongly with the age of onset of musical training (i.e., more activation with younger onset). Activation of the left PT was most pronounced in musicians with perfect pitch. In general, the PT is found to be larger (i.e., mean volume) in musicians in comparison with non-musicians (Schlaug 2003).

However, this does not appear to be true of all musicians, but only in the subgroup that have perfect pitch (Ross et al. 2005; Schlaug 2003; Zatorre 2003). Musicians with perfect pitch have a left-sided asymmetry and enlargement of the PT. The critical issues underlying the presence of perfect pitch remain unclear, but in most cases, it applies to musicians that started their musical training or were exposed to music before 7 years of age. The motor cortex has also been noted to have differences between musicians and non-musicians (Dawson 2011; Schlaug 2003). In musicians, there was enlargement of the right and left motor cortices, as measured by the sulcal length of the posterior bank of the precentral gyrus. The degree of enlargement was more pronounced in musicians that had begun musical training at a young age (i.e., before age 10) (Amunts et al. 1997). A similar study in right-handed violin players noted significant enlargement of the left motor and somatosensory cortices, in comparison with matched controls (Schwenkreis et al. 2007). Asymmetry of the motor and somatosensory cortices was highly correlated among the violin players. However, when performing non-musical tasks to test fine motor skills, the violinists performed similarly to the non-musician cohort. Using voxel-by-voxel MRI morphometry techniques, Gaser and Schlaug studied the brains of professional keyboard players, amateur musicians, and non-musicians (Gaser and Schlaug 2003). Gray matter volume was noted to be larger in the professional musician cohort, within the somatosensory cortex and the superior parietal cortex. There was also a strong correlation between gray matter volume in these regions and musician status, as well as the degree of practice intensity.

Some opossibly reflecting its greater musicalf these findings have been confirmed in a more recent study of professional pianists in China (Han et al. 2009). The pianist cohort had higher gray matter density in the left primary sensorimotor cortex and right cerebellum, in comparison with a matched non-musician group. In addition, the pianists also had higher fractional anisotropy (i.e., indicating higher white matter integrity) in the right posterior limb of the internal capsule.

Several groups have focused on white matter tracts and the plasticity of the brain in the context of musical training (Dawson 2011; Herholz and Zatorre 2012). It is now becoming clearer that musical training does induce brain plasticity within white matter structures, on a short-term and long-term basis. For example, the corticospinal tract has been studied by several investigators using diffusion tensor MRI. Bengtsson et al. (2005) studied 8 professional concert pianists and matched controls, and grouped them according to estimates on how much they had practiced during childhood, adolescence, and adulthood. Childhood practicing correlated with functional anisotropy (FA) in the bilateral limbs of the internal capsule, which include the corticospinal tracts, as well as the corpus callosum. The right posterior internal capsule was the only region with significantly higher FA values in the musician group compared to the non-musician group. Practice during adolescence correlated with FA in the splenium and body of the corpus callosum, while adult practice correlated with FA in the left anterior limb of the internal capsule, and possibly the right arcuate fasciculus. A similar report using diffusion tensor imaging techniques and fiber tractography studied professional musicians and controls, and found significantly lower FA values in the left and right corticospinal tract of the musician group (Imfeld et al. 2009). A right-greater-than-left asymmetry of FA was also noted, in both the musician and non-musician groups.

Among the musicians, diffusivity was negatively correlated with the onset of musical training in childhood, so that training with onset before age 7 was associated with increased diffusivity in comparison with the late onset subgroup and controls. Halwani et al. (2011) used similar techniques to study large white matter tracts, including the arcuate fasciculus, in professional singers, instrumentalists, and non-musicians (Halwani et al. 2011). Both singers and instrumentalists were found to have larger tract volume and higher FA in the right and left arcuate fasciculus in comparison with non-musicians. In comparison with the instrumentalists, singers had larger tract volume, but lower FA, in the left dorsal arcuate fasciculus, along with a similar trend for the left ventral arcuate fasciculus. In singers, the FA of the left dorsal branch of the arcuate fasciculus was inversely correlated with the number of years of vocal training. The same group has also studied the effects of instrumental musical training in young children over a 15 month period, using deformation-based MRI morphometry techniques (Hyde et al. 2009). In comparison with non-training controls, the training group developed increased volume within the motor cortex (i.e., hand area), corpus callosum, and the primary auditory areas over the 15-month testing period. The changes on the MRI scans were also correlated with improvements in musically relevant fine motor and auditory skills. Finally, there have been several studies evaluating how the brain analyzes rhythmical structure in musicians (Limb et al. 2006; Hyde et al. 2009). In the first report, an fMRI evaluation of passive rhythm perception between musicians and non-musicians, it was noted that a different neural network was engaged in the musician group (Limb et al. 2006). There was a left-sided lateralization of activation involving the perisylvian cortices, in particular the frontal operculum, superior temporal gyrus, and inferior parietal lobule. The authors suggested that musical training leads to the employment of left-sided perisylvian brain areas that are typically active during language comprehension, during passive rhythm perception activities.

A similar fMRI study evaluated the neural processing of rule-based rhythmic structure in jazz drummers and non-musicians (Herdener et al. 2014). For all subjects, deviations from the regular rhythmic structure activated the left PT, along with Broca's area and its right-hemispheric homolog. This is part of the same network that is critically involved in the processing of harmonic structure in music and the syntactic analysis of language. However, only in the jazz drummer cohort, there was additional activation of the left supramarginal gyrus, a higher-order region usually involved in the processing of linguistic syntax. These findings suggest that the processing of complicated rhythmical patterns requires the functional recruitment of brain areas usually dedicated to the processing of complex linguistic syntax.

2.2.4 The Neurology of Musical Performance

Performing music in general, and in particular at the professional level, is one of the most difficult and complex of human endeavors (Altenmüller 2008, 2010; Parsons 2001; Wiesendanger 2010). Musical performance requires the integration of multimodality motor and sensory information, along with precise monitoring of the motor performance by ongoing auditory feedback. The musician is required to reproduce highly controlled movements with extreme precision and reliability and is constantly assembling, storing, and improving complex sensorimotor programs. These specialized sensorimotor skills require extensive training over many years, often starting at a young age. For musical skills to be developed at such a high level, the student not only has to have the necessary innate neuromuscular skill-set to play an instrument, but also has to have a nurturing and supportive home environment, be exposed to and form relationships with engaging and talented music teachers, and have early experiences with music that promote intense and positive emotional experiences (Sloboda 1993). To acquire the skills necessary to perform music at a professional level (e.g., rock guitarist, classical violinist, jazz pianist, drummer, bassist), it is estimated that the minimal threshold amount of practice is approximately 10,000 h.

During the years of practice required to attain this level of skill, numerous brain regions become robust and many neural connections are established (i.e., musically induced brain plasticity) between the involved areas. As noted above, it is now well established that music practice can enhance myelination, gray matter growth, and fiber connections of brain structures involved in specific musical activities (Dawson 2011; Schlaug 2003; Herholz et al. 2012). The integration between sensorimotor and auditory cortical regions that develops after many years of practice is very strong. This has been demonstrated in an fMRI study of professional pianists, who were asked to listen to simple piano tunes without moving their fingers or other parts of their body, and to press the keys and play on a mute piano (Bangert et al. 2006). In comparison with the matched non-musician controls, while passively listening to the piano tunes, the pianists had activation of the appropriate motor (i.e., hand) and sensory regions as if they were actually playing the piano tunes themselves (i.e., motor co-representation). In addition, during the task of playing the mute piano, there was activation of an auditory association area between the temporal and parietal lobes that appears to function as an auditory–motor interface, translating the fingerings into the appropriate sounds.

A distributed cortical network was involved in both tasks, including the dorsolateral and inferior frontal cortex (including Broca's area), superior temporal gyrus (including Wernicke's area), supramarginal gyrus, supplementary motor areas, and supplementary premotor areas. This type of music practice-induced sensorimotor–auditory co-activation can even be followed in non-musicians completely naïve to instrumental music (Bangert and Altenmuller 2003). Non-musicians who had never played an instrument before were trained on a computer piano twice a week over a 5-week period. Mild auditory–sensorimotor EEG co-activity was noted even after the first practice session and was significantly enhanced over the 5-week training cycle. By the end of the training, similar to the professional pianists, the cohort would have increased activity in the central and left sensorimotor regions when passively listening to piano tunes and would also have increased activity in the auditory regions of both temporal lobes while playing a mute piano. Parsons and colleagues have performed a PET study to evaluate the neural activation patterns of professional piano players while performing a memorized Bach concerto versus a series of memorized major scales (Parsons et al. 2005). During both performances, there was activation of primary motor cortex, corresponding somatosensory areas, inferior parietal cortex, supplementary motor areas, motor cingulate, bilateral superior and middle temporal cortex, right thalamus, and the anterior and posterior cerebellum. Regions that were activated more specifically for the concerto included the superior and middle temporal cortex, planum polare, thalamus, basal ganglia, posterior cerebellum, dorsolateral premotor cortex, right insula, right supplementary motor area, lingual gyrus, and posterior cingulate. There were also some areas of deactivation noted for each performance, which were more prominent for the concerto, possibly reflecting its greater musical complexity and difficulty.

2.2.5 Jazz Musicians and the Neurology of Musical Improvisation

Jazz is a very popular and unique form of music, with distinctive melodic structure and chord progressions, and a propensity for improvisation over the top of the basic melody. Improvisational music is a very challenging and difficult form of music to master, requiring extreme musical creativity and understanding of chords and harmonic structure. In an attempt to analyze the neural mechanisms and networks involved in the process of improvisation, Limb and Braun used fMRI to study a group of professional jazz pianists (Limb and Braun 2008). The six pianists were studied while using their right hand to play on a keyboard during three separate tasks: playing the C major scale in quarter notes, playing the C major scale while improvising within the scale, and listening to an audio background, and improvising on whatever notes they wanted to play. It was theorized that the last task, with the most difficult and complex improvisational activity, would have a unique neural network and activation signature. However, the activation pattern and network activity was the same between the two improvising tasks, suggesting that low-level and high-level forms are handled similarly in the brain and that the activation was due to neural activity related to creativity, and not to the complexity of the task. Most of the fMRI changes occurred in the prefrontal cortex, a region of brain involved in problem solving and providing a "sense of self." Specifically, there was activation in the medial prefrontal cortex, an area that is important for "self-initiated" thoughts and behaviors, as well as the sensorimotor areas (see Fig. 2.9). In addition, there was suppression in the dorsolateral prefrontal cortex, which is responsible for monitoring one's own performance, as well as deactivation of limbic structures.

The authors speculated that this neural network signature may provide a cognitive context that allows for spontaneous creative activity. Other researchers using

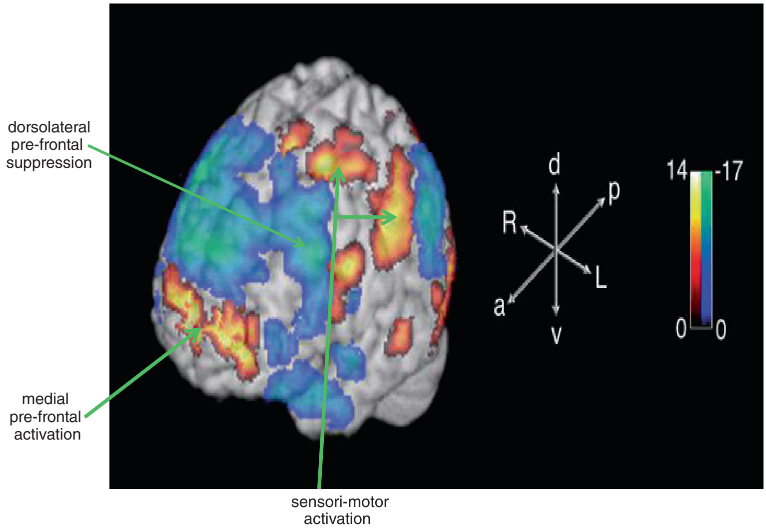

Fig. 2.9 fMRI study of a professional jazz piano player while improvising. The scan demonstrates activation in the medial prefrontal region (involved in "self-initiated" behaviors), as well as activation in the sensorimotor regions from instrumental motor activity. There is also suppression in the dorsolateral prefrontal region (involved in monitoring one's performance). Adapted from Limb and Braun (2008), with permission from the author

fMRI techniques and different experimental musical paradigms have also implicated the prefrontal cortex, but in the context of a somewhat different neural network (Bengtsson et al. 2007; Berkowitz and Ansari 2008). Bengtsson et al. (2007) had professional pianists play under several conditions: improvise on the basis of a visually displayed melody (and memorize the notes), reproduce the improvised song from memory, or freely improvise without memorizing the performance. In an attempt to isolate the brain regions involved in musical creation, they compared and contrasted the activation patterns between the three musical conditions, as well as at rest. The activated brain network included the right dorsolateral prefrontal cortex, the presupplementary motor area, the rostral portion of the dorsal premotor cortex, and the left posterior part of the superior temporal gyrus. In their study, Berkowitz and Ansari (2008) had professional pianists improvise both rhythmic and melodic note sequences (Berkowitz and Ansari 2008). The activated brain network in this setting included the dorsal premotor cortex, rostral cingulate zone of the anterior cingulate cortex, and the inferior frontal gyrus. As the above data would suggest, there seems to be a slightly different network of brain regions that become activated and suppressed in the context of musical improvisation, depending on the tasks and experimental musical conditions required of the musicians. Further research into this important aspect of musical creativity is ongoing, but the data appear consistent in showing that the prefrontal cortex is critical in the neural network that mediates the creative musical process (López-González and Limb 2012).

2.2.6 The "Mozart Effect" and Cognitive Aspects of Music

There have been many claims and suggestions in the literature that exposure to music, or at least to formal musical training, can have a beneficial effect on general cognition and non-musical aspects of cognitive function (Schellenberg 2003; Rickard et al. 2005). One of the first claims of this sort was by Rauscher et al. (1993), who reported that a 10-min exposure to a Mozart Sonata was able to induce short-term increases in spatial reasoning abilities (Rauscher et al. 1993). Each participant had to perform a series of tests of spatial abilities, and before each set of tests was either exposed to the Mozart Sonata, a relaxation tape, or total silence. The performances were improved after listening to the Mozart Sonata, but not after the other two conditions, and resulted in an IQ-score improvement of approximately eight points (i.e., half a standard deviation). Because this report came out in a prestigious journal (i.e., *Nature*) and suggested a direct effect on IQ, the popular press concluded that "listening to music can make you smarter." Critics of this research cite methodological problems that diminish the validity of the conclusions, in particular the choice of comparison conditions (Schellenberg 2003; Rickard et al. 2005).

Listening to a relaxation tape or sitting in silence does not have the same level of interest or arousal in comparison with listening to Mozart. In addition, mood is well known to influence performance on problem-solving tasks, with superior performance associated with positive mood and affect. Therefore, the findings could have also arisen from differences in mood alteration between conditions, rather than from the exposure to Mozart per se. Since the initial report by Rauscher, many other investigators have attempted to replicate the study, with mixed results and using a variety of spatial tasks. In some of the positively replicated studies, other music was used instead of Mozart (e.g., Bach, Schubert). Rauscher and colleagues have replicated the study as well, with limited positive findings that are similar to the original and feel that the studies with negative results were not using the proper spatial testing tools (Rauscher et al. 1995; Rauscher and Shaw 1998). A meta-analysis of studies related to the Mozart effect, including some unpublished data, concluded that the effect was only of moderate strength, but robust (Hetland 2000). However, many critics and skeptics are inclined to believe it stems from an "arousal or mood" modulating effect (possibly dopamine-dependent?), which is predominantly a right-hemispheric function, similar to tests of complex spatial abilities (Schellenberg 2003).

The cognitive benefits of formal musical training, especially in younger children, is a much less controversial and contentious area of research (Schellenberg 2003; Rickard et al. 2005). Musical training has been associated with improvements in mathematical performance, reading ability, spatial–temporal task performance, and general IQ in elementary school-age children. For example, in one study by Schellenberg and colleagues (2004), 6-year-old children were randomly assigned to a 36-week music training program for either keyboard or voice, or assigned to a control group with either no additional lessons or drama lessons (Schellenberg 2004). Children in the keyboard music lesson group and the Kodaly voice training group showed significantly greater improvements in full-scale IQ than did the children in the two control groups. More recent longitudinal studies have also been at least partially supportive of the basic premise that musical training in childhood has positive benefits for skills related to music (e.g., fine motor skills, auditory discrimination), as well as for important skills outside the sphere of music (e.g., vocabulary, nonverbal reasoning skills) (Schlaug et al. 2005; Forgeard et al. 2008).

However, some reports have not been supportive of this concept. For example, in an Italian study of adults, 21 skilled musicians and 21 age- and education-matched non-musician controls were studied using detailed neuropsychological testing (Giovagnoli and Raglio 2011). There was no difference in the test results between the musicians and non-musicians on any of the general testing areas, including attentive, executive, linguistic, perceptual, memory, or praxic functions. Other critics of this research also cite confounding, uncontrolled variables such as higher socioeconomic status of parents, advanced resources or extracurricular activities provided by the schools, or higher prior IQ as an explanation for the effect, rather than music training. It is obvious that more detailed, long-term longitudinal studies of elementary and junior high school-age children will be necessary before we can definitively answer this important question about the effects of musical training.

2.2.7 Neurological Disorders of Music and Therapeutic Applications

Neurological dysfunction related to the inability to process or enjoy music is called amusia (Peretz 1990, 2003, 2006; Stewart et al. 2006; Alossa and Castelli 2009; García-Casares et al. 2013). Neurological disorders related to music can be grouped into three general categories: acquired amusia, congenital amusia, and musicogenic epilepsy. Acquired disorders generally arise after some form of injury to the brain, which in adults is most commonly caused by a cerebrovascular accident or stroke (Stewart et al. 2006; Peretz 2003; Alossa and Castelli 2009; García-Casares et al. 2013). Other etiologies include traumatic brain injury, surgical resection, brain hemorrhage, various forms of focal and diffuse cerebral degenerative disorders (i.e., progressive amusia), and primary or metastatic brain tumors. Over half of the cases will have associated disorders of speech perception, and about a third will also have disorders of environmental sound perception. Within the domain of music, most of the acquired disorders will affect multiple aspects of musical perception and processing (Stewart et al. 2006). However, cases have been described of very isolated musical deficits, such as loss of pitch perception, temporal processing, timbral processing, mnemonic processing, emotional processing, and loss of recognition of familiar tunes. Very-fine-grained musical dissociations have also been described in these patients, such as between pitch contour and pitch interval, and between rhythm and meter. Loss of pleasure while listening to music is one of the most common presenting complaints in patients with acquired amusia. In many of these cases, the loss of pleasure is related to abnormal musical perception, so that the music seems "mechanical," "out of tune," or "the instruments sound dull." The powerful emotional responses to certain music (i.e., shivers) can also be lost after brain injury, especially damage to the medial temporal lobes and insula.

Congenital amusia refers to individuals with a lifelong inability to appreciate music and used to be referred to as "tone deaf" in the older literature (Peretz 1990, 2003, 2006; Stewart et al. 2006; Alossa and Castelli 2009; García-Casares et al. 2013; Stewart 2008). Congenital amusia appears to be a true perceptual agnosia, since the perception of music is abnormal in the presence of normal hearing and otherwise intact cognition. The main deficit seems to be in the perception and processing of pitch and pitch contour, with less consistent deficits in the perception of rhythm, temporal structure, and emotional responsiveness. Congenital amusics have severe deficits in the perception of absolute pitch, pitch direction, and pitch contour (Peretz 2003; Alossa and Castelli 2009; García-Casares et al. 2013; Stewart 2008). The most striking deficit was often in the ability to detect the proper pitch direction changes, which is critical for determining pitch contour and melody. However, this lack of processing of pitch contour related to music does not apply to the analysis of pitch changes relevant to speech (i.e., prosody). Patients may have difficulty with processing of meter and rhythm, and of "following the beat," but this is quite variable and may be mild or severe. Similarly, the loss of emotional responsiveness to music can also be quite variable in congenital amusia. MRI studies have not demonstrated any gross structural differences between congenital amusic and non-amusic individuals. The prevalence of congenital amusia is unknown, but is estimated to be 5 % or less. Familial cases of congenital amusia are common, and autosomal dominant inheritance with incomplete penetrance has been suggested in some cases (Stewart et al. 2006; Peretz 2003; Alossa and Castelli 2009; García-Casares et al. 2013; Stewart 2008).

Musicogenic epilepsy is defined as a type of reflex seizure disorder (i.e., precipitated by complex stimuli), in which the ictal event is induced by listening to specific songs or forms of music, often with a high emotional content (Peretz 2003; Murray 2010; Avanzini 2003; Maguire 2012). Scalp EEG recordings demonstrate focal epileptogenic discharges in the lateral and mesial temporal and orbitofrontal regions, often with a slight right-sided preponderance. The neural network responsible for linking the perception of music with the epileptogenic brain region is unknown. There is often a specific type or form of music that is peculiar to each patient as a stimulus for the epileptic event and can include certain instruments (e.g., piano, organ, church bells), types of music (e.g., rock and roll, symphonies), songs, and composers. For example, a recent case involved a 36-year-old man who reported partial seizures since the age of 24, every time he listened to emotionally charged music (Pittau et al. 2008). He underwent video-EEG recordings and fMRI while listening to "neutral" and "emotionally charged" music. During the epileptogenic music, three right temporal seizures were recorded. On fMRI, there was activation of the primary and secondary auditory cortices during the "neutral" music. However, during the "emotionally charged" musical passages, there was activation of the same auditory cortical areas, as well as widespread activation over the right frontotemporal-occipital region before onset of the seizure.

The most relevant therapeutic application of music is the field of music therapy, which has been an accepted component of Western medicine since the 1950s, but has been applied throughout the world in various forms since antiquity (Davis and Gfeller 2008; Koelsch 2009). The modern field of music therapy has been shown to be beneficial in children and adults, and for many disease states, including depression and anxiety, developmental disabilities, exercise and physical therapy, stroke recovery, tolerance of chemotherapy, and pain control (Gfeller and Thaut 2008; Thaut et al. 2008; Richardson et al. 2008; Bradt et al. 2011; Chan et al. 2011; Särkämö and Soto 2012; Clark et al. 2012). Although the exact mechanisms of the therapeutic benefit of music therapy remain unclear, it is thought to be related to the ability of music to engage multiple brain areas and neural systems within the patient, including attention, sensory processes, memory-related processes, perception-action mediation (i.e., "mirror neuron system" activity), multisensory integration, emotional processing, and the processing of musical syntax and meaning (Koelsch 2009).

2.2.8 Neurobiological Model of Music Processing and Summary

A more recent and complete model of the neural processing of music has been proposed by Koelsch and Siebel (2005) and includes several interesting and novel features (see Fig. 2.10) (Koelsch and Siebel 2005). After the musical acoustic

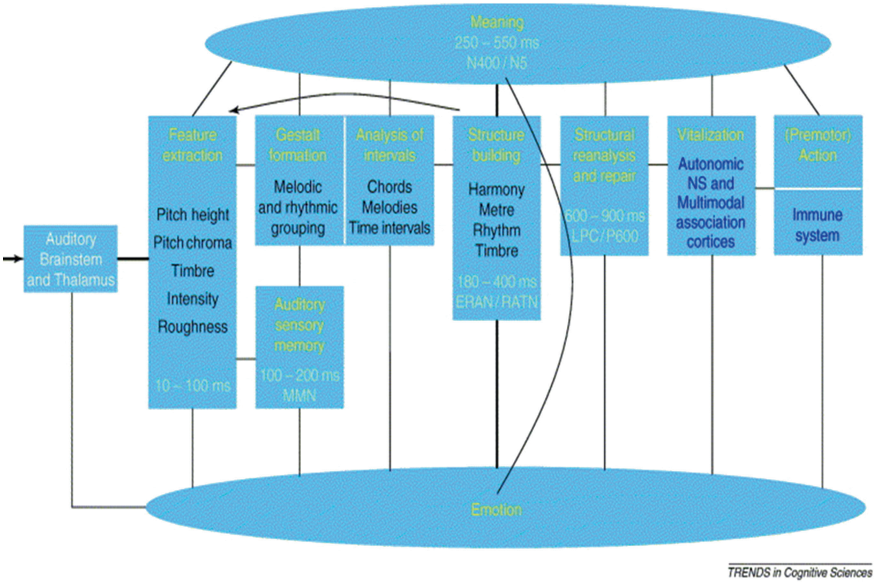

Fig. 2.10 Neurocognitive model of music perception and processing, as proposed by Koelsch and Siebel. After the musical auditory signal goes through initial auditory processing in the brainstem and thalamus, it goes through a series of compartmentalized processing steps, along with analysis for "meaning" and "emotion." See text in Sect. 2.8 for further details. Adapted from Koelsch and Siebel (2005)

signal has passed through the middle ear and cochlea, there is preprocessing of the composite signal in the superior olivary complex and inferior colliculus for pitch, timbre, intensity, and other features. Once the signal reaches the thalamus, it is directly connected to the amygdala and medial orbitofrontal cortex, which are implicated in emotional responses and control of emotional behavior. After the thalamus, the signal is then transferred to the primary and secondary auditory cortices, where more specific musical processing occurs in regard to pitch, pitch height, timbre, sound intensity, etc.

The time course for this initial processing in the auditory cortex is estimated to be between 10 and 100 ms. After the basic auditory features have been delineated, the acoustic information enters auditory sensory memory, within a time frame of 100 and 200 ms, which is thought to be in the inferior frontolateral cortex. In parallel to this, the acoustic information also enters into a compartment the authors call Gestalt formation, where the musical signal is grouped according to basic elements of melody, rhythm, timbre, and spatial characteristics. This is important for proper grouping of the musical signal and to be able to recognize it and follow it as an "acoustic object," with a cognitive representation. Closely linked to the stage of Gestalt formation, there is a more detailed analysis (i.e., analysis of intervals) of the acoustic signal in terms of pitch intervals, pitch directions, chords, pitch contour, melody, and temporal intervals.

Pitch contour and melody processing are predominantly mediated in the posterior part of the right STG, while processing of pitch intervals and direction involves the posterior and anterior regions of the supratemporal cortex bilaterally. The PT is also involved in the processing of pitch intervals, pitch direction, and sound sequences. After the analysis of intervals stage, on a time course of between 180 and 400 ms, there is a process of structure building, in which the musical signal goes through final processing for harmony, meter, rhythm, timbre, and temporal features. This is the process of musical syntax, where chords and harmonies are analyzed in terms of the preceding harmonic and musical context. This is a very automatic neural feature and is present in non-musicians as well as musicians, although it is developed to a much more rigorous and sophisticated level in trained musicians. Musical syntactic processing occurs predominantly in the pars opercularis of the inferior frontolateral cortex bilaterally, as well as in the anterior portion of the STG and the ventrolateral premotor cortex. In the next compartment of structural reanalysis and repair, with a time course of 600–900 ms, musical syntactic violations (e.g., abnormal chord progressions or notes out of the expected pitch contour) are determined and applied to the ongoing analysis of the acoustic signal. In parallel with the analysis of musical parameters and structure, there is an overlying process to determine "meaning" of the musical acoustic signal, with a time course of 250–550 ms.

The musical meaning could entail aspects of common forms or patterns in the music (e.g., jazz, symphonic, country, specific composers), emotional context of the music (e.g., happy, sad), social or other non-musical context (e.g., national anthem, college fight song), or meaning related to specific aspects of musical structure (e.g., unexpected chords). Similarly, from the initial phases of acoustic processing and onward, and at every stage of the model, there is input into the large bottom compartment of "emotion," whereby the listener has to develop an emotional reaction to the musical signal, which can range from complete revulsion, to neutral apathy, to spine-tingling chills. Late in the time course of music processing is the compartment of "vitalization," in which the body may or may not have a physical response to the music (e.g., autonomic arousal), along with cognitive integration of musical and non-musical information (e.g., emotional responses, tense, relaxed). The integration process most likely occurs in the parietal association cortices. The final compartments involve possible motor responses to the musical acoustic signal, such as tapping a finger or foot, dancing, or singing. Neuro-immunological aspects are also included, since strong emotions tied into listening to music may influence the secretion of immunoglobulins (e.g., IgA). This model is a more robust and complex approximation of the process of music perception in comparison with older models and includes novel compartments that have been overlooked in the past (e.g., gestalt formation). However, further refinements are still needed to broaden and improve the model so that it emulates the complexity of the process in the human brain.

Significant progress has been made over the past 20 years in deciphering the neural mechanisms involved in the processing of music in the brain. Most of these advancements have been driven by the availability and application of new, non-invasive neuro-imaging techniques including PET, fMRI, and MEG. Ongoing technical refinements in these neuro-imaging modalities (e.g., stronger magnets, improved signal-to-noise ratios) will allow for even more detailed exploration of the brain and neural networks related to music. However, it is also clear from the literature cited above that even when using the exact same techniques (e.g., fMRI) and studying the same parameters (e.g., pitch, timbre), the activation patterns and associated neural networks may be similar, but often have subtle differences, as long as the investigators are using different experimental paradigms and conditions. Nonetheless, music remains a very rich avenue of exploration into the inner workings of the brain, since it involves so many different cortical and subcortical regions and neural networks. Important questions that still need to be addressed in future research include more detailed aspects of the neurobiology of musical performance, musical learning, and the process of musical composition.

In addition, further work needs to be done on the question of how the brain creates and then subsequently recognizes musical Gestalts and which neural networks mediate this activity. How does the primary and secondary auditory cortex decode and finalize processing of musical acoustic signals? How does the neural perception of music interact with the autonomic nervous system, hormonal systems, and immune system? How do the different musical processing compartments interact with each other and how does each of them interact with the musical lexicon (i.e., music-specific memory stores)? And finally, further research is needed into the various ways in which music can interact with emotion, both positive and negative. There are powerful links between specific songs in the musical lexicon and emotional responses, as well as between emotions and new music we are exposed to on a daily basis. It will be important to further clarify the neural networks and circuitry underlying the connections between powerful emotions, musical listening, and musical memories.

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Chapter 3
Music Therapy: Bettering Lives One Note at a Time

Alejandra J. Ferrer

Abstract The present chapter discusses the field of music therapy and the benefits that individuals of all ages and levels of functioning obtain from participating in music therapy sessions. A literature review pertaining to music therapy with the clinical populations of oncology, mental health, gerontology, medical/surgical, and developmentally disabled was presented. Music therapy is an effective adjunct therapeutic modality that can support clients in achieving goals of a cognitive, physical, emotional, and social nature. Music therapy professionals are highly skilled clinicians trained in the areas of general music, psychology, and therapeutic principles. Their broad education supports them in designing unique and creative music-based interventions. While music therapists view the profession as a dynamic, therapeutic process consisting of interactions among the music, therapist, and client, it is impossible to deny the intrinsic qualities of music and its benefits upon the human spirit. The present chapter ends with a discussion regarding the use of music in our personal lives.

Keywords Music therapy · Psychology · Medicine · Creative music-based interventions

3.1 Introduction to Music Therapy

Within the general public, the perception of music can vary from that of an artistic and complex notational language to a fundamental source of entertainment. While music is all of this, it is also a creative, evidence-based therapy provided by allied healthcare professionals to individuals facing challenging situations. The goals of providing this unique therapeutic modality are many and include promoting emotional healing, relieving a variety of physical symptoms, and improving quality of life.

A.J. Ferrer (✉)
Nationwide Children's Hospital Columbus, Columbus, OH 43205, USA
e-mail: Alejandra.Ferrer@nationwidechildrens.org

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The use of music for the treatment of disease is not a new concept. In ancient times, chants, incantations, and rhythms were used by priests and witch doctors to heal physiological or psychological ills believed to have been caused by evil spirits. For thousands of years, it was assumed that music possessed supernatural powers which could heal the sick directly or through a higher force such as a tribal God (Gfeller 1990). Historically, Native Americans have used singing and chanting as part of their rituals, and ancient Greek philosophers believed that music could heal both body and spirit. Since the late 1800s, the applications of music in medicine have been studied by the scientific community in a systematic fashion (Hyde 1924; Cherry and Pallin 1948; Ellis and Brighouse 1952; Locsin 1981; Charlesworth and Nathan 1987; Wiand 1997) and results of these studies have repeatedly demonstrated music's effectiveness in ameliorating a variety of conditions. With the establishment of music therapy as a formal field of study through the implementation of the first music therapy curriculum in 1944, the use of music as therapy in medical hospitals, schools, mental health facilities, and other treatment centers dramatically increased.

3.2 Overview of Music Therapy

The profession of music therapy recently celebrated 60 years of remarkable history. Having been formalized as a field of study in the 1950s with the establishment of the National Association for Music Therapymusic therapy, approximately 5,300 board certified music therapists serve clients all over the United States in present times (Certification Board for Music Therapists 2011). The American Music Therapy Association which functions as the governing body for the profession defines music therapy as "the clinical and evidence-based use of music interventions to accomplish individualized goals within a therapeutic relationship by a credentialed professional who has completed an approved music therapy program" (http://www.musictherapy.org/about/musictherapy/). In simpler terms, music therapists are allied healthcare professionals who utilize music-based interventions to help clients achieve goals of a cognitive, physical, emotional, and social nature.

In a medical setting, a music therapist may utilize receptive music listening to refocus a patient's attention as they undergo a medical procedure. The goals may include decreasing the patient's perception of pain, state anxiety, and providing a positive coping mechanism. In a physical rehabilitation setting, a music therapist may work with a stroke patient to improve eye–hand coordination, range of motion, gross and fine motor skills, laterality, and directionality. To accomplish these goals, the music therapist provides the patient with a variety of musical instruments, each requiring a unique set of motor skills. As the patient engages in playing these instruments, the music therapist supports the exercises by providing patient-preferred live music. The music enhances motivation, provides structure, and connects with the patient on multiple levels.

Similar to other healthcare professionals, music therapists assess their patients' level of functioning. Based on this evaluation, individualized goals are determined, and a treatment plan is developed. Throughout the delivery of the treatment, the music therapist constantly evaluates the client's responses and reactions, making necessary adjustments, and documenting progress. Music therapists are an integral part of the patient's interdisciplinary treatment team, utilizing creative interventions for goal achievement. The most commonly used music therapy interventions include receptive music listening, songwriting, vocal and instrumental improvisation, song discussion, moving to music, and singing. Music-assisted imagery, deep breathing, and progressive muscle relaxation are also incorporated into the repertoire of music therapy techniques.

A common misconception about the field of music therapy is that the music by itself produces the desired changes in the client. Often, the music is described as a powerful, "magical" tool. While music therapists recognize the intrinsic positive qualities of music, they are also fully aware that it is the dynamic relationship between the music, the therapist, and the client that result in the desired outcomes. Bruscia (1998) describes music therapy as a process that is systematic, purposeful, methodical, temporally organized, knowledge-based, and regulated. Therefore, a predetermined "reason" exists for the delivery of music therapy services. This "reason" is what guides the music therapist in drawing from their knowledge of music therapy theory and professional experience to design the most appropriate plan of action.

3.3 Populations Served by Music Therapists

Today, music therapists are employed in a variety of healthcare facilities, and many are an integral part of the patient's medical management or interdisciplinary treatment team. Music therapists serve over 60 different clinical populations including individuals with developmental disabilities in settings such as schools, rehabilitation, and vocational centers; the Alzheimer's and dementia populations in places such as nursing homes and adult day care facilities; medical/surgical populations including cancer patients, individuals with physical disorders, sensory impairments, stroke, and neurological disorders as for example Parkinson's and traumatic brain injury; children and adults with mental illness, including individuals with behavioral disorders, eating disorders, emotional disturbances, psychosis, forensic status, post-traumatic stress, and substance abuse problems; hospice patients; at-risk children and adolescents; individuals in jails and prisons; and people of all ages seeking wellness and a better quality of life.

3.4 Education of a Music Therapist

In order to best serve a wide variety of patient populations, the education of music therapy students must provide significant breadth and depth across multiple areas of study. The undergraduate music therapy curriculum is designed to impart entry-level competencies in areas related to core music studies (music theory, history and literature, applied lessons, secondary instruments, conducting, and ensemble practice), clinical foundations (therapeutic principles, exceptionality and psychopathology, and human development), and music therapy (music therapy foundations, principles, methods and techniques, client assessment and evaluation, music and special populations, psychology of music, and supervised practica and clinical internship). Liberal arts coursework and electives complement the described areas (AMTA 2006). Once students satisfactorily complete the coursework, including 1,200 h of clinical training that encompasses community practica during the final two years of study and a six month, supervised internship, the student becomes eligible to sit for the music therapy board certification exam, a national assessment tool based on the Certification Board for Music Therapists' (CBMT) *Scope of Practice*, which "defines the body of knowledge that represents competent practice in the profession of music therapy and identifies what an MT-BC (Music Therapist-Board Certified) may do in practice" (www.cbmt.org/upload/CBMT_SOP_2011.pdf). Today, more than 70 colleges and universities offer bachelors, masters, and doctoral degrees in music therapy. These training programs are approved by the American Music Therapy Association and the National Association for Schools of Music.

3.5 Relationship Between the Creative Process and a Therapeutic Exercise

Unlike traditional therapists (psychologists, social workers, and mental health counselors), expressive arts therapists (music, art, and dance/movement, and drama) are in a fortunate position when it comes to merging creativity with the therapeutic process. It could be easily stated that one does not exist without the other: Creative arts therapists utilize various creative processes and artistic expressions to help their clients accomplish a variety of therapeutic or non-artistic goals.

As an adjunct to more traditional forms of therapy, the expressive arts therapies are widely used to improve the lives of individuals of all ages and levels of functioning. Art therapists use art and traditional psychotherapy to "treat and to remediate those psychological problems that interfere with adaptive functioning" (Rubin 1999, pp. 67–68). A variety of techniques such as painting, sculpting, drawing, photography, collage, and mask and mural making are employed in the therapy sessions. As described before, music therapists utilize musical activities such as singing, playing instruments, listening to music, writing songs, and analyzing song lyrics to facilitate the therapeutic process (Davis et al. 1999). According to the American Dance Therapy Association, dance therapists use body movement to "promote emotional, cognitive, physical, and social integration of individuals" (http://www.adta.org/). Similarly, drama therapists utilize drama and/or theater processes (storytelling, improvisation, and enactment) to achieve a variety of therapeutic goals (National Association for Drama Therapy 2011).

The expressive arts therapies provide a unique creativity component that traditional verbal therapies do not possess. Creative arts therapists often lead their clients to reflect and connect with their deepest thoughts and emotions. Clients can easily give meaning to everything they do and feel. Expressive arts therapists relate to their clients in very profound and beautiful ways. The creative medium, whether dance, music, art, or drama, is so powerful that it often speaks for itself.

3.6 Background

As described earlier, music therapists provide services to a variety of clinical populations. Over the last 60 years, numerous research studies have been conducted in the areas of special education, medicine, mental health, gerontology, and end of the life. These studies demonstrate music therapy's viability as an effective form of therapy. Over the next several pages, a summarized review of the literature concerning five clinical populations widely served by music therapists will be provided.

3.7 Medical/Surgical

The use of music in medical settings has undergone a reawakening since the 1980s, confirming the mutual interdependence between music and medicine and giving to music therapy the needed credibility as a professional discipline. The better understanding of the use of music with various medical populations (i.e., maternity, obstetrics, oncology, rehabilitation, psychiatry, surgery, pediatrics, intensive care, cardiac rehabilitation and general medical) has enriched the theoretical field of biomedicine, resulting in partnerships between college and university music therapy programs and the institution's or city's medical hospital. The Biomedical Theory of Music Therapy is intended to provide a practical foundation for professionals in both music and medicine to proceed with research and clinical applications of music in medical procedures (Taylor 2007).

In the medical setting, music therapists have evaluated the effectiveness of music therapy intervention on pain, anxiety, mood, affect, need for analgesic medication, immunity, and quality of life. These variables have been studied in a variety of medical patients including oncology, AIDS, non-malignant syndromes, sickle cell disease, neurodegenerative disorders, cardiology, stroke, and pediatrics. Results of these studies demonstrate that music therapy is a powerful intervention in decreasing pain perception, anxiety, and nausea (Madson and Silverman 2010); promoting feelings of well-being (Weeks and Nilsson 2011), improving shortness of breath, mood, affect, and positive verbalizations (Gallagher et al. 2006); reducing distress (Noguchi 2006); increasing relaxation, decreasing fatigue, and stabilizing heart rate (Chuang et al. 2010); reducing rates of nausea and emesis (Ezzone et al. 1998), decreasing cortisol and increasing salivary immunoglobulin A levels (Burns et al. 2001); and successfully eliminating the need for sedation during certain types of medical procedures (DeLoach Walworth 2005).

Music therapy in the medical setting is used to address the physical and psychosocial needs of patients. Physical needs concern problems such as pain, physical rehabilitation, heart rate, blood pressure, respiration, nausea, and vomiting. Psychosocial needs concern the patient's emotional and social functioning. Music therapy interventions are tailored to help patients cope with the fear and anxiety that often result from an illness and specific treatment and to identify ways to better adapt to the illness and its limitations. Interventions are also designed to provide patients with cognitive stimulation, social interaction, and positive, enjoyable moments that normalize the hospital stay (Davis et al. 1999). According to the American Music Therapy Association (2006):

> Research results and clinical experiences attest to the viability of music therapy even in those patients resistant to other treatment approaches. Music is a form of sensory stimulation, which provokes responses due to the familiarity, predictability, and feelings of security associated with it (http://www.musictherapy.org/assets/1/7/MT_Medicine_2006.pdf).

3.8 Music Therapy in Oncology

Numerous studies have demonstrated the effectiveness of music therapy interventions in the oncology setting. For cancer patients, music therapy can serve as a powerful tool to decrease anxiety (Ferrer 2007), elevate mood (Burns et al. 2001), reduce pain perception (Huang et al. 2010), promote creative self-expression (Tobia et al. 1999), and improve quality of life (Hilliard 2003). Music therapy interventions can enrich the life of cancer patients and serve as a vehicle to abandon or step outside of the cancer diagnosis; even if for just a short period of time. A variety of music therapy interventions have been researched with the purpose of determining their therapeutic effectiveness when utilized in the oncology setting. Listening to preferred music, writing songs, pairing music and pleasant images, and playing instruments are some of the most commonly used music therapy interventions.

The conjoint use of music therapy and cognitive behavioral therapy (CBT) has also resulted in reducing negative symptomatology in critically ill cancer patients. CBT entails manipulating thought processes in order to "modify overt and covert disturbed behavior." Cognitive behavioral therapists propose that an individual's thoughts, judgments, perceptions, self-statements, and even unconscious

assumptions have a direct effect on their behavior. Therefore, *cognitive restructuring* (modification of thought patterns believed to be causing negative behaviors or disturbed emotions) will result in a positive behavior change (Davison et al. 2004). Magill et al. (2008) found that critically ill cancer patients who received combined CBT and music therapy had a significant reduction in distress levels. As part of the music therapy intervention, the therapists used song lyrics and personalized them to the patients, asking participants to share how the song related to them while discussing associated memories and emotions. The feedback gained through the song discussion was then used to reframe cognitive distortions and to generate hope and coping. This study serves as an important example of how two distinct professions can collaborate and facilitate client recovery.

3.9 Mental Health

Mental health refers to emotional, cognitive, and social well-being in terms of proper expression of thoughts and feelings, adequate ways of handling stress, and the ability to relate to others and make healthy choices. The present definition of mental health incorporates more holistic terms including the capacity to enjoy life by creating a balance between leisure activities and constant work, family, and environmental demands, and efforts to achieve psychological resilience following difficult experiences. Many professionals stress that mental health is not only the mere absence of mental disorders. The World Health Organization (WHO) defines mental health as "a state of well-being in which the individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community" (http://www.who.int/mediacentre/factsheets/fs220/en/). Stedman's Medical Dictionary defines mental health as "a state of psychological well-being in which one has achieved a satisfactory integration of one's instinctual drives acceptable to both oneself and one's social milieu" (http://www.medilexicon.com/medicaldictionary.php?t=39451). Through these definitions, it is evident that the construct of mental health is multidimensional in nature.

When behavior, thoughts, and feelings are unexpected, bizarre, or self-defeating, disorders may appear in the form of mental illnesses. According to the National Institute of Mental Health (2012), approximately 57.7 million Americans (or 26.2 % of adults) suffer from a mental health disorder in a given year. However, the main burden of illness is concentrated in about 1 in 17 individuals (or 6 %). It is estimated that half of all the people who suffer from a mental health diagnosis probably suffer from another mental disorder at the same time.

In the mental health arena, the effects of music therapy have been studied on problems such as behavioral disturbances, psychosis, mood, coping skills, and motivation. Despite there being limited research literature in this area, the results of the studies that have been published indicate that music therapy is an effective form of therapy for this client base.

In a study by Gold (2007), adult psychiatric patients diagnosed with schizophrenia or schizophrenia-like psychosis who participated in individual music therapy sessions as part of their care showed greater improvements in symptoms of psychosis as compared to those patients who received standard care. In an earlier investigation, Gold et al. (2006) systematically reviewed four music therapies and mental health studies and found that music therapy was effective in improving the global state of individuals diagnosed with severe mental illness, including their general mental state, negative symptoms of the illness(s), and social functioning. A correlation was found between the number of sessions and the improvement of symptomatology, indicating a dose–effect relationship. Weber (1996) studied the effects of relaxation exercises on the anxiety levels of hospitalized psychiatric patients. Results of the study indicated that anxiety was significantly reduced when patients used coping mechanisms such as meditative breathing, progressive muscle relaxation, and guided imagery and soft music.

In a meta-analysis of 19 quantitative studies concerning music therapy with psychiatric patients, Silverman (2003) found that a variety of music activities including live music, recorded music, patient-preferred music, therapist-selected music, structured music therapy groups, and passive music listening experiences had significant effects in suppressing psychosis-related symptoms. The conclusions from this meta-analysis suggest that when working with psychiatric patients, one music intervention may not be significantly more effective than another, and therefore, multiple avenues can be taken to work on specific goals while truly tailoring an intervention to fit a patient's individual needs and musical preferences. A unique finding of this meta-analysis was that popular music had a greater positive impact on patients' symptoms as compared to classical music.

In order to properly apply an official nomenclature to a wide diversity of contexts, the American Psychiatric Association has provided the *Diagnostic and Statistical Manual of Mental Disorders* (DSM), a classification system that encompasses clinical disorders, personality disorders, mental retardation, general medical conditions, psychosocial, and environmental problems. The manual also offers a section of the main mental health disorders of old age such as delirium, dementia, and other cognitive conditions.

Over the next section, two principal types of brain disorders of the elderly will be examined. The implications of music therapy on the health and quality of life of this population will also be discussed.

3.10 Dementia, Alzheimer's Disease, and Music Therapy

According to the DSM-IV-TR (2000), the disorders under the term "dementia" are characterized by the development of multiple cognitive deficits (including memory impairment) that result from the direct physiological effects of a general medical condition, the persisting effects of a substance, or multiple etiologies (e.g., the combined effects of cerebrovascular disease and Alzheimer's disease). In all types of dementia, the individual's intellectual functioning declines, and memory, abstract thinking, and judgment deteriorate. Most types of dementia are progressive, and in later stages of the disease, the individual may perceive him or herself as a different person, becoming oblivious to their environment, family, and friends.

Alzheimer's disease, the most common form of dementia accounting for 50–80 % of all dementia cases (Alzheimer's Association 2012) is a serious, progressive, and irreversible illness. The disease manifests itself through symptoms related to memory impairment (impaired ability to learn new information or to recall previously learned information) and the presentation of one or more of the following cognitive disturbances: (a) aphasia (language disturbance), (b) apraxia (impaired ability to carry out motor activities despite intact motor function), (c) agnosia (failure to recognize or identify objects despite intact sensory function), and (d) disturbances in executive functioning (i.e., planning, organizing, sequencing, and abstracting information) and (DSM-IV-TR 2006).

Extensive reviews of empirical studies concerning the use of music therapy with the Alzheimer's/dementia population document the importance and effectiveness of the use of music in the therapeutic process. Brotons, Koger, and Pickett-Cooper (as cited in Prickett 2000, p. 308) identified and categorized 30 research articles and presented the following conclusions:

> (1) Patients diagnosed with Alzheimer's disease and related dementias can continue participating in structured music activities late into the disease; (2) Instrument playing and dance/movement are preferred activities, both by patients and in terms of ability to participate even into the later stages of the disease; (3) Modeling of the patient's expected response increases participation; (4) Individual and small group settings are most useful; (5) Social/emotional skills, including interaction and communication, can be enhanced; (6) Cognitive skills can be enhanced; and (7) Music interventions can be an alternative to pharmacological or physical restrain.

Other studies have demonstrated that music therapy is effective in reducing the rates of depression among older adults (Hanser and Thompson 1994), decreasing the frequency of negative behaviors such as agitation and aggression in patients with Alzheimer's/dementia (Clark et al. 1998; Gerdner 2000), enhancing memory recall, heightening arousal, improving attention span (Simmons-Stern et al. 2010), and promoting language functioning and skills (Brotons and Kroger 2000).

In sum, music therapy plays an essential role in the lives of patients with Alzheimer's/dementia, and most facilities with gerontology units employ music-related activities. Music therapy fosters a sense of control, self-efficacy, and strengthens self-concept in older adults. Even those with severe cognitive impairments are able to successfully participate in music therapy sessions, replacing feelings of loss with energy, joy, and hope.

3.11 Music Therapy for Children with Developmental Disabilities

The Centers for Disease Control and Prevention define developmental disabilities as a group of "severe chronic conditions that are due to mental and/or physical impairments" (http://www.cdc.gov/) and manifest themselves during childhood prior to the age of twenty-two. Developmental disabilities may affect an individual's language, mobility, learning, and the ability to self-care and live independently. According to the National Institute of Child Health and Human Development (2011), developmental disabilities can be categorized into four groups: nervous system disabilities, sensory-related disabilities, metabolic disorders, and degenerative disorders.

Nervous system disabilities affect how the brain, spinal cord, and nervous system function, impacting intelligence, behavior, movement, language, speech, and learning. The most common nervous system disabilities include Down syndrome, fragile X syndrome, and autism. Sensory-related disabilities affect an individual's hearing, vision, and other senses and are often associated with other developmental disabilities. Examples include deafness and cataracts of the eye due to congenital rubella and sensitivity to loud noises resulting in overreactions or outbursts as observed in children with fragile X syndrome.

Metabolic disorders affect the individual's metabolism; in other words, the way a person's body builds up, breaks down, and processes the materials needed for proper functioning. Two examples of metabolic disorders that result in intellectual and developmental disabilities when left untreated include childhood hypothyroidism and phenylketonuria (a metabolic disorder in which the body is unable to process a portion of the protein phenylalanine (Phe) found in almost all foods).

Degenerative disorders can affect physical, mental, and sensory functioning. Often, the infant appears normal at birth but overtime loses various functions as a result of the underlying condition. Degenerative disorders are sometimes a product of metabolic disorders. The most common ones include Rett's syndrome (a disorder in which individuals exhibit low muscle tone, autistic-like behaviors, and hand movements consisting of waving or wringing) and Duchenne muscular dystrophy, a disorder characterized by rapid muscle degeneration (Muscular Dystrophy Association 2011).

Though a cure does not exist for most developmental disabilities, treatment options such as occupational, speech, and physical therapy can often improve the level of functioning for many individuals. Behavioral therapies such as dialectical behavior therapy (DBT) and applied behavior analysis (ABA) are also often used to treat behavioral symptomatology related to developmental disabilities.

The profession of music therapy serves as an advocate for children and adults with special needs. In the American public school system, music therapy is considered a special education-related service, put in place to support students' learning and skill acquisition. Music therapy provides cognitive, physical, emotional, and social stimulation for children with disabilities. Skills practiced and learned through music can then be transferred to the academic setting or to the child's daily routines (Standley 1996). In terms of cognitive enhancement, singing, for example, serves as a creative way to develop a child's memory. Through the repetition of melodic and rhythmic patterns, the retaining of academic material can be improved (Claussen and Thaut 1997; Wolfe and Hom 1993). Using music therapy interventions as rewards also supports attention span and concentration ability in children with a variety of diagnoses including autism and attention deficit and hyperactivity disorder, which in turn improves learning in the classroom (Rickson 2006).

In terms of physical enhancement, singing can increase lung capacity and strengthen the diaphragm, improving overall respiratory functioning for the child. Selected verbal language and speech skills are also impacted in a positive manner (Braithwaite and Sigafoos 1998; Buday 1995; Gold and Wigram 2006). In addition to singing and playing instruments, moving to music helps to develop gross motor skills that can support the child with activities of daily living. Music therapy interventions may also be designed to promote muscular relaxation in children with cerebral palsy, promoting overall relief of pain and muscle tension.

As with other clinical populations served by music therapists, individuals with developmental disabilities do not need to have any special musical ability nor formal musical training to benefit from music therapy sessions. While participation in individual or group music therapy is of great benefit to the student with special needs, of equal benefit is the integration of the student into the general music classroom. Mainstreamed learning serves as a normalizing and empowering experience for all involved. Students of different levels of functioning can learn together and collaborate on common goals. This is of utmost importance for students with profound disabilities who often receive their education in a contained classroom, rarely having opportunities to interact in meaningful ways with their typically developing peers (Humpal 1991).

3.12 Overview of Two Approaches in Music Therapy: Nordoff-Robbins and Behavioral Music Therapy

3.12.1 Nordoff-Robbins Music Therapy (NRMT)

The Nordoff-Robbins or creative music therapy approach is based on the assumption that within each human being, there is an inborn musical self or a "music child" that can be awakened through improvised music-making between the client and therapist. As the music therapist stimulates the innate musical capacity of the client, he/she facilitates resolutions of psychological difficulties. Central to the Nordoff-Robbins approach are Rudolf Steiner's ideas concerning music intervals and music archetypes which emerge from his anthroposophy philosophy. The anthroposophical approach suggests that by using the musical elements of tones, intervals, rhythms, melody, harmony, mirrored tone-sequences, and movement-supported sound patterns, a therapist may promote growth in the client's musical emotional awareness; resulting in increased integration and organization of the individual's physical, cognitive, and spiritual forces (Nordoff-Robbins 1977).

"Nordoff-Robbins clinicians focus on long-term therapeutic growth, which is characterized by expressive freedom and creativity, communicativeness, self-confidence, and independence" (Aigen et al. 2004, p. 72). Originally, Nordoff-Robbins techniques were used with children with various developmental disabilities to teach new skills, concepts, and improve communication. Currently, the approach has expanded to adult populations, including those under medical, psychiatric, and geriatric care. Through the Nordoff-Robbins approach, clinicians respond to "a client's personality using musical improvisations that suit the mood of the moment, and musically describe the client's facial expression and physical bearing" (Aigen et al. 2004, p. 72). Through close evaluation, the therapist "observes a client's movements and sets them to music; chants songs that describe the client's actions, moods, or experience; and imitates the sounds that the client makes using instruments or voice" (Aigen et al. 2004, p. 72). It is through active involvement in live, interactive music that the therapist and client communicate, emotionally connecting, sharing attention and awareness, and experiencing meaningful musical dialogues.

3.12.2 Behavioral Music Therapy

Supported and developed by E. Thayer Gaston and other early music therapy pioneers, behavioral music therapy conceives music as a kind of learned human behavior; its goals being to modify unwanted behaviors using music interventions as reinforcement. The use of strict experimental procedures to study observable behavioral responses in relation to environmental stimuli led to consider behavioral music therapy practitioners as somewhat radical and empirically oriented, reducing the music therapy process and research to modify only overt behaviors, leaving little room to uncover mental processes, and rejecting the idea that behavior disorders were symptoms of hidden emotional conflicts. An examination of the behavioral techniques commonly used in music therapy practice would surpass the goals of this chapter; however, the most basic techniques including shaping, modeling, task analysis, chaining, and successive approximations will be reviewed.

Through *shaping*, a behavior can be targeted, observed, reinforced, and moved until the desired behavior is obtained. By *modeling*, "the behavior that is to be taught is demonstrated for the learner, and any semblance of the desired behavior is initially rewarded. The criterion for reinforcement is then gradually increased until the goal behavior is obtained" (Madsen and Madsen 1998, p. 318). *Task analysis* is the process of breaking down a complex behavior into small, achievable components or parts. *Chaining* is the process of joining two or more responses in a systematic fashion, by presenting one at a time until all can be linked into a complex behavioral sequence. As each new behavior is added, the entire sequence to that point is repeatedly practiced. Madsen and Madsen (1998) define *successive approximations* as "behavioral elements or subsets, each of which more and more closely resembles the specified terminal behavior" (p. 323).

With the passage of time, behavioral music therapy music therapy received influences from aspects of social learning theory, which is based on the interaction of three systems: environmental stimuli, positive and negative reinforcement, and cognitive mediation. Born from behavioral theory, social learning theory relies on assessment and remedial programs based upon the environmental control of behavior; however, cognitive processes mediate between the environmental influences, including how they are perceived and interpreted by the individual. Presently, music therapists of this orientation utilize a more cognitive behavioral approach rather than solely behavioral principles (Standley et al. 2004).

3.12.3 Self-empowerment Through Music

The use of holistic therapies has been on the rise for the last number of years. In present times, individuals of all ages and walks of life seek alternative therapies such as acupuncture, massage, reflexology, and yoga to promote the well-being of their bodies and minds. When contemplating the use of music for increased wellness, the discussion is always one of hope, as music has the ability to positively impact the individual; research from various sources, including neurologists, psychologists, music therapists, and other healthcare professionals confirm music's profound positive effects on body and spirit.

The present chapter discusses the field of music therapy and the benefits that individuals of all ages and levels of functioning obtain from participating in music therapy sessions. A literature review pertaining to music therapy with the clinical populations of oncology, mental health, gerontology, developmental disabilities, and medical/surgical was presented. While the American Music Therapy Association defines music therapy as "the clinical and evidence-based use of music interventions to accomplish individualized goals within a therapeutic relationship by a credentialed professional who has completed an approved music therapy program" (http://www.musictherapy.org/about/musictherapy/), we must keep in mind that engaging in music in our personal lives can also lead to important health benefits that contribute to overall physical, emotional, cognitive, and social well-being. As individuals, we can use music as a form of self-empowerment or healing practice. For example, we can listen to music to increase energy levels when feeling drained, for catharsis when dealing with emotional stress, or for relaxation purposes following a difficult day. The possibilities for using music in our personal lives are endless.

Utilizing music as a form of self-care can lead to overall wellness by supporting emotional regulation and the management of stress. Listening to fast-paced music helps to promote focus of attention, energy, and motivation during the completion of daily, ordinary tasks. Slow music can promote a relaxed mood by decreasing heart rate, respiration rate, and blood pressure. Slow-tempo music may also be used during meditative practices, to facilitate sleep, and as a form of positive distraction when experiencing physical pain. Listening to inspiring song lyrics (versus instrumental music) immediately results in a more positive outlook, improving an individual's mood by fostering hope and bringing on a sense of calmness and peace.

Recent scientific advances have demonstrated music's direct effect on brainwaves. Music with a strong beat can stimulate brainwaves to resonate "in sync" with the beat. As mentioned before, faster beats support concentration and result in more alert thinking. Slower beats induce a calmer, more meditative state. The brainwave response to music can result in important changes for an individual dealing with anxiety, depression, or anger. Essentially, an individual can strategically select specific songs to support different moods or states of mind.

Scientific research validates the human response to music both from a physiological level to overt behavioral responses. Studies have demonstrated that when individuals listen to their favorite music, particularly when delivered live, a "cocktail" of feel-good chemicals including prolactin, dopamine, and oxytocin are released by the brain. The biological stress response is also affected in a positive manner by music, and studies have shown that reduced levels of the stress hormone cortisol follow exposure to music. Immunity also appears to be positively impacted by music. In a study where individuals actively engaged in drumming activities, increased levels of natural killer cell activity and reduced levels of cortisol were reported. Considering the results from the scientific research and our own personal experiences, it is not difficult to assimilate the positive health benefits one can obtain from making music a part of daily life. It is empowering to know that one will feel better following exposure to music.

Photographer: Lindsey Holmes, MT-BC, Columbus, Ohio

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Chapter 4
Enhancing Creativity Through Group Art Therapy

Anne Harding

Abstract This chapter describes how embracing other creative modalities and incorporating coping skills and inherent strengths within group art therapy can not only provide expression and processing of emotions in an effort to enhance well-being, but also promote and enhance a more creative lifestyle. The use of creative thinking and actions can enhance a person's life at any age, both in the workplace and in the home environment and can be infused into an everyday lifestyle. However, it can be particularly challenging to incorporate creative endeavors into everyday life after a significant life event such as a serious medical diagnosis. This chapter also provides synopses of several art therapy program sessions and half-day workshops in an oncology setting. Interventions were designed to assist patients or participants in thinking "outside the box" as a way to identify and express their emotions around treatment and diagnosis and also to assist participants in reframing their lives with the inclusion of a cancer diagnosis by using creative art therapy interventions. Participants were encouraged to use innovative, creative techniques to express themselves in hopes that they would continue to explore creative means of expression beyond the workshops. A description of the field of art therapy and group therapy and some basic principles of art therapy practice are also provided as background information to those unfamiliar with the field.

Keywords Art therapy · Creativity · Meaning-making · Positive psychology · Savoring · Empowering

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A. Harding (✉)
The James, The Ohio State University Wexner Medical Center,
James*Care* Survivorship, Columbus, OH, USA
e-mail: Anne.Harding@osumc.edu

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4.1 Introduction

As an art therapist who works in group settings in two very different clinical settings, I have observed that while art therapy is a powerful modality, the addition of other creative modalities and practices to the facilitation of art therapy are most effective in awakening the creative spirit and hence assisting people on the journey to wholeness. This chapter explores some of the innovative methods or "non-methods" I have used as an art therapist to fan the flames of creativity in an effort to guide people forth on their own journeys of self-discovery and healing. It has been my experience that supplementing the art therapy process with additional creative tools helps people not only to explore their raw emotions related to an illness or lifestyle change, but to empower them in all other areas of their lives as they seek to "make meaning." In this chapter, I will provide examples of how creativity is fostered within single-group art therapy classes, themed five-week series support classes for oncology patients and also within half-day workshops created specifically for outpatient cancer survivors and their caregivers.

While fostering a sense of empowerment in many areas of life during time-limited art therapy interventions may seem a lofty goal, an inquiry into the expressive arts as therapy will demonstrate that this type of art therapy can yield richness of meaning-making. If creativity is thought of as free-flowing expression, then art therapy can be thought of as a faucet with which to turn it on. Embedded in this free flow is the untapped unconscious which may contain valuable insight for those dealing with unexpressed emotion. Gaining access to this flow through creative acts such as those implemented in art therapy may bring the unconscious forth to the surface to examine. This can provide rich material to draw upon to gain greater understanding of self, enhancing emotional health if processed well through individual or group therapy. The backbone of "making meaning" of life through the use of art therapy is creativity in its finest hour, providing sustenance for the heart, mind, and soul. "As we engage the unconscious and imagination in creative processes, we experience ourselves as active participants in life, explorers with the power to reshape our responses to our life stories rather than the victims of our circumstances" (Halprin 2003, p. 88).

There are many types of effective arts programs within medical facilities including artists-in-residence, volunteer art programs, and expressive arts programs. Often, community arts programs also provide an outlet for those seeking a way to express themselves and their emotional needs through art and are embraced by local medical facilities. The programs described here were facilitated through a comprehensive cancer center hospital survivorship program. As a board-certified art therapist, I developed and facilitated the sessions as part of the arts programming provided for cancer survivors and caregivers. Therefore, both a description and a basic background of art therapy are provided as a backdrop for a better understanding of the type of programs that can be offered through a medical facility that embraces the use of art therapy as an effective complementary modality for supportive outpatient care for survivors and their caregivers.

4.2 What Is Art Therapy?

For the purposes of this chapter, the definition of art therapy used is the established definition by the American Art Therapy Association (AATA 2012) Art therapy is:

> a mental health profession that uses the creative process of art-making to improve and enhance the physical, mental and emotional well-being of individuals of all ages. Research in the field confirms that the creative process involved in artistic self-expression helps people to resolve conflicts and problems, develop interpersonal skills, manage behavior, reduce stress, increase self-esteem and self-awareness, and achieve insight.
>
> Art therapy integrates the fields of human development, visual art (drawing, painting, sculpture, and other art forms), and the creative process with models of counseling and psychotherapy. Art therapy is used with children, adolescents, adults, older adults, groups, and families to assess and treat the following: anxiety, depression, and other mental and emotional problems and disorders; substance abuse and other addictions; family and relationship issues; abuse and domestic violence; social and emotional difficulties related to disability and illness; trauma and loss; physical, cognitive, and neurological problems; and psychosocial difficulties related to medical illness. Art therapy programs are found in a number of settings including hospitals, clinics, public and community agencies, wellness centers, educational institutions, businesses, and private practices.

4.2.1 What Training Is Necessary to Become an Art Therapist?

A professional art therapist must hold a master's level degree in art therapy or in a related field with additional training in art therapy in order to practice. AATA (2012) provides registration for individuals who have completed the requirements for an art therapy degree from an institution that has been approved by AATA. Those who have fulfilled requirements for those institutions which are not approved by AATA or are waiting for approval are required to provide additional documentation to ensure complete coverage of study areas and also are required to complete additional supervised hours upon graduation. The American Art Therapy Credentials Board, Inc. (ATCB 2012) provides board certification testing for those who are registered art therapists through AATA. Those who take and pass the ATCB board test are provided board certification status with 5-year renewal requirements in order to stay certified. Like most mental health professions, art therapy has requirements for continuing education courses or workshops to stay abreast of the field. While AATA and ATCB provide national standards for art therapists, regulations and requirements for art therapists to practice vary from state-to-state with some states requiring a state license to practice art therapy from their respective state licensure boards (AATA 2012; ATCB 2012).

Professional art therapists are trained in art therapy theory, psychotherapy, individual and group counseling techniques, ethics, standards of practice, human development, multicultural issues, a variety of art modalities, research methods, and more. Practicum experiences in varied settings must be completed as well. Art therapy training also includes cultural diversity training to assist in being aware of one's own prejudices and biases. Similar to other types of therapeutic, psychological, or counseling fields, art therapists are expected to seek assistance or provide a referral when working with someone outside their own scope of knowledge and training, having developed sensitivity and an understanding of gender, race, cultural, and economic differences (ATCB 2012).

While registered art therapists have specialized training in art therapy and psychotherapy, they may make use of a variety of other arts such as writing, drama, music and dance, and play therapy to enhance or complement their practice. Making use of these tools may have some similarities to the way an expressive arts therapist might conduct a session. Additionally, art therapists may choose to co-facilitate groups or collaborate with trained music therapists, theater, poets, writers and artists, social workers, or counselors as well as medical staff and community arts organizations.

4.2.2 Diagnosis or Dialogue?

The use of art therapy as a diagnostic tool has been at times both the bane and the boon of art therapy since its inception as a field and much discourse has been written on this. Some art therapists are hired primarily to use art therapy as a diagnostic tool, while in other settings, art therapy is used for expression after the diagnosis is made by a primary physician, psychiatrist, or psychologist. An art therapy assessment or projective test may be used as a diagnostic tool or simply to provide more information to the art therapist and treatment team in order to prepare a treatment plan. However, the art assessment is still nearly always accompanied by conversation with the individual. If art therapy is deemed to be an appropriate modality for the patient, it is likely to be a complementary therapy alongside other disciplines.

Regardless of the setting of the art therapy practice, many art therapists say they are frequently asked, "Can you tell me what my picture or artwork says about me?" An art therapist is likely to refer the question back to the person, with a reply such as "That is for you to discover. Tell me, what do you see when you look at your piece?" While art therapists are specifically trained to look for "clues" in content, color, line, shape, form, etc., it is important that they not be too quick to draw conclusions. This may be because their response may be based in part on their own experiences, their own reality, projections, and/or their personal cultural norms. Dialogue around the artwork can provide valuable information including bringing in the creator's own perspective on the importance of including certain images, shapes, lines, and colors, and even how they may choose to downplay vital information referring to them as "accidents" or "mistakes." These conversations can provide missing links that the image or artwork alone may not provide even to the most trained eye.

When a therapist or other practitioner is too quick to interpret a patient or participant's artwork without feedback from the creator, questions might arise about what the basis is for the analysis and even at times about the scope of training of the therapist or practitioner. For instance, I can recall witnessing a psychology professor interpret his students' drawings without any discussion with them prior to his "diagnoses." Although I was not yet an art therapist, I was dismayed that someone would make assumptions based purely on their own cognition. The impressionable students were then left to process his analysis, or more correctly interpreted, his "reading" of what type of young men and women they were. My only hope was that they would soon forget what he "professed" to be his expert opinion. Just as first impressions are not easily forgotten, words shared related to one's personal images can be powerful and lasting. Therefore, careful consideration should be taken in discussion around the image or art object in both an individual and a group setting. The professional art therapist is carefully trained to speak thoughtfully about the artwork, guiding the client to come to their own conclusions without unduly influencing their perceptions.

In addition to guiding the artist/creator to respond to his/her own artwork, a professionally trained art therapist will be able to assist group members in responding to others' works in a way that is helpful and not hurtful. This does not mean that there may not be difficult conversation around an image or artwork or that group members will not challenge one another to grow or change or to view things in a new light. Posing the phenomenological question, "What do you see?" is one basic technique frequently used to assist viewers in responding to their own work or the work of others (Betensky 1995). Another helpful technique can be to "become" something in the image created and give it a voice. For instance, "If you were the cat, dog, tree, rock, apple, or whatever image, color or shape in the picture evokes further questions what would you be saying right now?" (personal communication with art therapist D. Jones, 2004). The creator of the image or artwork may also choose to give the piece a title which sometimes reveals the essence of the work. Or they may "see" a subliminal personal message engraved or emblazoned on a stone, a road sign, in a book, a gift, or other image within the artwork. This message can then be received as feedback from the psyche or soul to the creator.

Many times the process alone is the therapy, and words are not necessary as the image or object itself gives voice. McNiff (1998) reminded both art therapist and artist of the importance of an image or object being allowed to stand alone, giving voice through its very existence. He also emphasized that the art materials be allowed to speak, revealing their characteristics during the process. In my work as an art therapist, I frequently encounter individuals who have created powerful images that they know speak volumes in terms of emotion and meaning. Yet words do not suffice to describe what has taken place, nor are always they necessary. Even though words can enhance the meaning, validate feelings and further deepen meaningful dialogue between group participants, the process of creating the piece alone can be the more powerful task. While it is the art therapist's desire to assist the patients/participants in accessing and integrating meaning, it is also up to the therapist to be cognizant of when less is more. Clients are often encouraged to spend time with their artwork after the group or individual session. Sitting with their artwork for days or even months down the road, the client may come to see something more clearly or see something completely new that was previously hidden to him or her. Making the invisible visible can be nearly instantaneous, or it can be a very lengthy and complex process.

More recently, research in neuroscience and in positive psychology has increasingly shown the necessity of providing other positive sensory experiences with which to help those in treatment replace difficult feelings with positive emotions by integrating them into their lifestyle (Hass-Cohen 2008; Seligman 2011). In *Flourish*, Seligman described how he sometimes assisted his clients in getting rid of anger, anxiety, sadness, etc., assuming that they would then be happy, hence "cured" patients. Eventually, he came to the realization that without providing tools for them to replace difficult emotions with more positive ones, he simply ended up with an "empty patient" (p. 54). While Seligman, a strong advocate for positive psychology, encouraged a focus on strength building, he also recognized that it was important not to exclude working through difficult emotions in the process of working toward self-actualization, or empowerment, but that striking a balance in practice was the key. Hass-Cohen viewed art therapy as one of many mind–body interventions that could aid in the restoration of the sympathetic–parasympathetic balance by lessening stress. He indicated that research around brain plasticity reveals potential for the brains of adults to be able to rewire and adapt more than was previously thought. Hass-Cohen further stated that the self-expression and therapeutic relationship of art therapy could provide coping tools that could be generalized into the client's environment beyond the sessions. This has great potential for therapists to be able to provide interventions which can assist in lessening stress and trauma by providing experiences which can essentially reframe traumatic life experiences (Hass-Cohen). Wilkinson and Chilton (2013) further advocated a combination of art therapy with positive psychology to assist practitioners in moving individuals beyond the processing of difficult emotions or distress, to a state of empowerment, or flourishing.

It is therefore a daunting task, if not a high calling of the art therapist to facilitate the expression of difficult emotions within a group setting as well as to provide additional coping and strength-building tools. How best can one apply the therapeutic tools of creative expression, regulation of emotion, and incorporation of life-enhancing skills within a group? Some of the programs described are endeavors to creatively combine and apply art therapy techniques using various expressive modalities alongside coping and strength-building exercises which encourage positivity. It is hoped that by doing so, the resulting art sessions can foster an environment conducive to self-expression, healing, and a sense of well-being. The combination of art therapy and other exercises are not necessarily exclusively for use in an oncology setting. They may be adapted to other settings such as mental health or drug and alcohol rehabilitation. They were originally designed and facilitated, however, specifically for adult oncology art therapy groups in an outpatient setting.

4.3 Why Group Art Therapy?

While much may be gained by the client through individual art therapy, it is often not considered cost-effective and also is not covered by health insurance in many states. Nor is the "average" patient who is undergoing major medical treatment or life crises usually readily equipped to pay for what may be considered an unnecessary or even frivolous expense when coupled with the many hidden expenses that frequently accompany even the most basic treatment. Therefore, complementary therapies, while deemed helpful, may fall to the bottom of the list of priorities when in reality, they may be most beneficial in restoring a healthful standard of living to those who have undergone traumatic experiences such as a cancer diagnosis and treatment (Puig et al. 2006; Reynolds and Prior 2006; Svensk et al. 2009). In addition to being cost-effective, group therapy has many advantages over individual therapy. Yalom (1995) elucidated some of the benefits of providing therapy within a group setting into eleven primary therapeutic factors. Of these factors, those in Table 4.1 are most commonly utilized within the oncology group art therapy setting as observed by this author.

In an oncology group art therapy setting, the most notable of Yalom's (1995) eleven therapeutic factors are the instillation of hope, group cohesiveness, and catharsis. Existential factors also invariably come into play as well, as individuals attempt to make meaning of their experiences. Hope is not only an important factor to promote, regardless of diagnosis, but essential for the art therapist to emulate so that group members may see modeled life-enhancing skills in the face of adversity and promote hope among one another. One of the primary reasons individuals may be reluctant to participate in "talk therapy" support groups is because they feel like there is much focus on treatment, diagnosis, and others' experiences sometimes to the exclusion of what to do to maintain hope (Schmitt and Harding 2011). Even as group members share their deepest fears metaphorically, verbally, or wordlessly through image, the atmosphere and group presence honors the feelings yet conveys an air of hope to the individual. This "healing" presence of hope may not be healing in the traditional sense, but can provide a sense of recognition and sense of wholeness having been acknowledged. "Hope is conveyed artistically, verbally, behaviorally, and metaphorically" (Moon 2010).

Table 4.1 Some of Yalom's primary therapeutic factors observed within an oncology group art therapy setting

• Instillation of hope
• Universality
• Imparting information
• Altruism
• Interpersonal learning
• Group cohesiveness
• Catharsis
• Existential factors

Note Based on information from Yalom (1995)

While instillation of hope and being involved with group members who have had similar life experiences may be significant factors in wanting to join such a group, great care must be taken that individuals are not secondarily traumatized as they hear or view others' stories whether shared bluntly or in metaphor. The metaphor, a powerful tool in art therapy, to be expounded upon later, can sometime leave more overwhelming and more powerful impressions than the sharing of a straightforward narrative. As the group progresses and becomes more cohesive, catharsis may occur during sharing or even during the process. It takes a skillful therapist to modulate this catharsis within the group so that all members can make meaning of their resulting emotions as a result of experiencing and supporting the person emoting without losing a sense of hope in the process.

4.4 Art Therapy and Creativity

It may seem that creativity is inherent in the field of art therapy by virtue of the fact that those practicing art therapy and those who are the benefactors of the therapy use art as the modality in which to express themselves. It is the concern of the author, however, that the art-making of art therapy in a clinical setting is often expected to be reduced to a formula to be completed in a specific time with limited materials not unlike a standardized projective art therapy test. Art therapists in hospital, psychiatric, or other clinical settings are often asked to work within rather constricted guidelines and materials with short-term goals in which the expectation is that the problem will be addressed and if not "fixed," better controlled. Clinical art therapists may be expected to provide "standardized" outcomes that can be measured on a Likert, or similar scale, with success being determined by formulaic answers that show "significant" results. It is the art therapist's responsibility to find a way to enhance creativity in spite of conditions that may not be an ideal format or time frame in which to create or process artwork. This sometimes take creative thinking on the part of the therapist to work both within the parameters of the institution's regulations, following protocol, yet maximizing creative potential for participants.

While art therapy facilitated within clinical settings can often provide identification and expression of subconscious or unconscious needs, fears, anger, sadness, and other emotions related to the presenting issue, it often opens the door to healing in other capacities as well. This author contends that the real work of the therapist is not only to assist the patient or participant in identifying and expressing the concerns that brought the patient/participant into art therapy, but also to awaken latent creativity; provide tools to help the patient/participant to learn to live in the moment; utilize positivity in everyday living; to savor past and present treasured moments; to address spirituality issues brought on or exacerbated by diagnosis or an illness or life crises as well as to encourage empowerment of the individual. Likewise, Moon (2010) stated, "I am more focused on encouraging the creative flow of group members' self-expression than on trying to determine the cause of their problems and attempting to solve them" (p. 88). He further stated that since few emotional problems have single causes it can be more transformative to provide creative, life-affirming art therapy experiences which provide insight into the "essential concerns" (p. 88). As individuals mindfully learn to access and express emotions around the "bigger picture," it can bring insight to the presenting cause as well.

Art therapist, Shaun McNiff (2004) ascertained that while it is possible to attain desired results by "following the medical/diagnostic approach of controlled and strategic interventions, applying a certain type of expression to a particular malady" (p. 134), he preferred the use of a more creative process, which he stated was "often perverse, illogical, and totally contrary" (p. 134). He further stated, "Healing through art is ultimately about living in tune with the creative spirit" (McNiff, p. 135). When we attend to information accessed through creative expression using the arts, we can become more aware of the world around us. If one believes this, then the key is how to "tune in" or to awaken to this creative spirit within. Art therapist and expressive arts therapist Ellen Levine (2003) likened creativity to a fire within and described the therapist as one who assists in tending the fire. Levine stated, "I see how important it is that creativity is part of the healthy functioning of all individuals and of societies as well. It makes us more flexible and less rigid, more open and less defended, and provides more comfort with darkness, pain and frustration" (p. 14).

4.4.1 Enhancing Creativity by "Going with the Flow"

Much research has been dedicated to the flow aspect of creativity (Cameron 1992; Csikzentmihalyi 1990; Seligman 2011). Csikzentmihalyi coined the use of the word "flow" as way to describe the process of being so deeply engaged in art-making as to produce a sense of timelessness. How does the flow aspect apply to art therapy in a clinical setting where frequently the topic and exercises of a group session are predetermined? In the clinical oncology outpatient setting, it is important that within the structure, there are built-in flexibility allowances. The opening exercises are structured so that group members can quickly move into the "flow." Therapeutic interventions are provided that assist participants in leaving presenting cares "on the page." This allows them to be able to move into a deeper process and to be more emotionally present with the exercises that follow. Sometimes, depending on the type of warm-up exercise and the affect of the participants, the "creativity zone" is so close to the surface that the opening exercise alone will take them to this place.

It is not unusual for group members to become so completely absorbed in their artwork in sessions that they lose track of a sense of time and place until processing time. It is imperative that the therapist does not rush the group members to complete their artwork during a session. Even though group processing time is part of each session, individuals can dialogue about a work in progress without feeling pressured to complete their artwork in a set time frame. While this may squelch "flow," knowing that their work is respected and that they can continue to work after the session lends itself to promoting creativity beyond the time frame of the program. It is not unusual for the art therapist to lend art materials so that participants can continue working at home in settings where this is possible. Often, the group process of sharing with one another even partially finished pieces may provide them with insight which may be of value when they complete their work on their own time. In my workplace, group members frequently bring completed pieces back at a later date to get technical assistance, glean additional insight, or simply to share their creations.

One of the goals of oncology art therapy groups is for the individual to return to a "new normal" by restoring, renewing, or discovering new joys and pleasures in addition to making meaning. Exploring new techniques beyond the sessions, discovering new arts modalities, and exploring community art resources are encouraged. Over the course of many years, I have observed this wakening or re-awakening of latent or prior interests in the arts in participants many times. Former group members have become museum docents, yoga instructors, prolific, or casual writers and artists. When introduced to a new technique, individuals are encouraged to further explore the medium on their own if it lends itself well to their self-expression. Hence, some past participants of group therapy are now quite proficient in silk painting, doodling, painting still lifes, watercolor painting, journaling, poetry, pastel drawing, and more. This ability to transfer knowledge and move beyond the original experience can be life-transforming (Schmitt and Harding 2011).

4.4.2 Incorporating Mindfulness into Art Therapy

Monti et al. (2006) conducted an eight-week trial study making use of mindfulness meditation within an art therapy group setting. This randomized, controlled trial addressed the psychosocial needs of oncology patients and the stress inherent in the diagnosis and treatment. Symptoms of distress and quality of life related to health issues were measured providing significant statistical results supporting the incorporation of mindfulness techniques into art therapy groups for cancer patients. In my practice, I have made use some of the principles of mindfulness meditation using a number of references and resources. Kabat-Zinn's (2007) *Arriving at Your Own Door: 108 Lessons in Mindfulness* contains material which can be of value to patients/participants who are seeking to live in the moment by providing short one-page quotes or lessons which provide food for deeper thought around being mindful in daily living. Patients/participants sometimes make use of these and other quotes as part of their altered books or collages, illustrating their commitment to consciously live in the present. In *Full Catastrophe Living: Using the Wisdom of Your Body and Mind to Face Stress, Pain and Illness,* Kabat-Zinn (1990) provided many coping skills for those dealing with mental or physical stressors in their lives. Exercises that I often make use of include the mindful breathing exercises, body scan exercise, or the mindful meditation to set the stage for art therapy work. I may use mindful meditation or imagery to close a session if it has been a particularly deep or emotion-evoking session. Creatively presenting stress reduction tools as an enhancement to art therapy can allow participants to be more mindful in their art-making as well as in their daily living beyond the sessions.

Guided imagery from various sources and mindful attention to, or meditation upon, nature such as wooded areas, prairies, gardens, bodies of water, flowers, and other natural forms have been found to elicit responses which assist in drawing close to one's inner nature (London 2003). While not easy to accomplish in a clinical setting, I have attempted to bring nature into therapeutic sessions by employing fruits, vegetables, and nature items such as pinecones, acorns, branches, flowers, and leaves as still life items, props or as art supplies for natural art sculptures. At times, participants may be asked to meditate upon an item such as a flower or a leaf. Creating a simple painting or pastel drawing of one piece of fruit or vegetable can lead to a discussion on simplicity, body form and physical changes related to cancer, the cycle of life, imperfections or attachment to perfection, spirituality, or any number of topics that may come up in the course of drawing or painting. Attention to color, line, shape, or detail, whether the work is abstract or realistic can lead to process around a multiplicity of emotions or even a conversation around a lack of emotion.

One art exercise in a five-week series class for oncology patients titled, "Seasons of Life" was to take home a rose and observe its changes daily by sketching, drawing, or journaling. Drawing various images of the rose was a way to explore changes in their own body as well. While not as ideal as being out in nature, bringing nature into the session can be of assistance in guiding participants to renew a connection with nature and help to restore balance. "The creation of art is not some esoteric activity of a gifted few; it is the natural way of forming meaning whenever important issues are addressed sincerely" (London 2003, p. 59). In a half-day workshop titled "Up Close and Personal," participants were asked to choose either a natural item or a photo of a nature item and select one small portion through a viewfinder to reproduce as a painting. These paintings served as a reminder to look at both the details and also the bigger picture in life. Those who completed these paintings shared insights they gained during the process of painting. As the study by Reynolds and Prior (2006) indicated, art-making can assist individuals in maintaining or reconstructing their identity after cancer. Coupled with a return to nature through art-making, it is the author's contention that this connection may further strengthen the individual's identity by promoting a positive connection with the natural world.

Another art program which focused primarily on nature and exercise, but included a therapeutic art component was an observational walk in natural settings such as nature parks or woods during which participants observed nature close-up and also as a panoramic view. Literary and art quotes or passages referring to nature by authors such as Thoreau, Dickinson, and Emerson, as well as Haiku and other types of poetry were read along the way by the nature guide who has a strong background in art as well as nature. Interesting trivia on wildflowers, trees, wildlife, birds, and fish was also be shared. As the attending art therapist, my role was to encourage visual or written journaling by suggesting drawing, sketching, or painting with various media, as well as to provide other art activities such as making tree rubbings or leaf prints or writing haikus or other poetry. Times were provided for self-reflection and sharing at various points along the way and at the end of each walk. Mindful attention to the sights, smells, sounds, textures, and the world around them during these walks added to their enjoyment and also provided a sense of balance and restoration. While not specifically art therapy, the therapeutic benefits in this type of program were similar as participants could make connections through artistically observing nature and the accompanying metaphors whether or not they created an artwork. This reconnection with nature and interaction with others in settings such as these may also help the participant return to the "new normal."

4.4.3 The Role of Spirituality in Group Art Therapy

Regardless of whether the therapist or the participant of an art therapy group intends to address spirituality, it is a topic that appears repeatedly within the oncology outpatient art therapy group. Images which seemingly are completely unrelated to the topic of spirituality may take on a life of their own, with angels, demons, and other mystical or visionary creatures or beings appearing consciously unbidden by the artist. Colors, lines, or shapes can take forms which are suggestive of something beyond the ordinary. How then does the individual confronting their own humanity and perhaps questioning their current views on spirituality and religion make sense of these? The interrelatedness of art and healing and spirituality are undeniable. Whether a person dialogues with the presenting images, befriends them, journals or reflects or meditates upon the works as they come forth, most contemporary art therapists contend that the images or objects and the messages they convey are invaluable resources to seeking wholeness and meaning to life (Farrelly-Hansen 2001; McNiff 2004; Moon 2010).

Malchiodi (2002) stated, "Images are a central source of meaning-making because they flow from your inner creative authority, the soul's palette" (p. 29). She further postulated that these images could be autobiographical in many dimensions, revealing values and beliefs among other things. Images or objects created within an art therapy group can be a rich source of material from which to sort out ambivalent feelings around spirituality that may occur as a result of a traumatic life experience. Whether addressing spirituality directly such as creating a spiritual mandala or through dialogue about or with images seemingly unrelated to the topic, the therapeutic group process can provide a forum for thoughts on spirituality to be expressed or assimilated. Sculptor and teacher, Nancy Azara (2002) made use of a combination of meditations and art directives to open the door to "make meaning" of life and the deeper issues of our place in the world. "When spirit takes form, the healing properties and magical qualities inherent in art-making take shape, holding its presence in the work of art, and speaking to the viewer with its radiance" (Azara, p. 83).

From an existential art therapy standpoint, it is the willingness to accept things as they are or embrace them upon reflection of the art piece that is important rather than the dissection or labeling of the artwork. Moon (2009) recommended approaching the artwork with a sense of wonder, inviting conversation with the piece. He suggested that the disturbing elements that may crop up in an artwork be used as an expression which needed to appear in order to promote healing. McNiff (1992, 2004) took an even more radical approach by advocating dialogue with the artwork as an entity, angel, or shaman, viewing the artwork as an autonomous being who still embodied characteristics of the creator. Additionally, McNiff (2004) suggested the use of other art modalities such as performance art to allow the image or artwork to speak. This multimodal approach embraces the use of imagination and can allow the participant to process beyond what simple reflection might do. Obviously, great attention must be paid to the mental stability and ability of the participant or patient who is guided in this direction by the art therapist when exercising this method of viewing.

4.4.4 Making Use of Savoring in Art Therapy

Savoring may seem to be antithetical to living in the moment. However, according to Bryant and Verhoff (2007), savoring can actually be referenced in three forms: the past as in reminiscing, the present as in mindfully being aware, and the future as in anticipation of good things. Savoring can be attached to associated sights, sounds, smells, taste and touch and ambience. Regardless of whether accessing past, present, or future in an art therapy setting, this technique can be used as a powerful way to create optimism, far beyond simply coping. Additionally, in a group setting, individuals can live "vicariously" through experiencing others' pleasures as they share their stories through art images. Examples of the use of savoring in art therapy interventions can be found in the workshops provided as examples. Group members who I have worked with in sessions have frequently shared that they glean satisfaction from hearing others' favorite memories and could often relate better to others in the group as a result. For instance, when asked to draw and then share around a savoring theme such as "draw a favorite summertime memory" or "draw a favorite vacation memory" participants could re-experience their own feelings of joy, serenity, or satisfaction and could experience others' positive sensory memories as well.

4.4.5 The Power of Metaphor in Art Therapy

Metaphor can be a powerful way to access emotion and is used extensively in art therapy (Malchiodi 2002; McNiff 1998; Moon 2009). Individuals currently in treatment for cancer and those beyond treatment may sometimes say they are acutely aware that they have emotions around their diagnosis, but cannot seem to find words for them (Schmitt and Harding 2011). Likewise, those in treatment for drug and alcohol rehabilitation or mental health issues may know they are angry, depressed, fearful, anxious, and so forth, but have either been medicated or have self-medicated to cope with their feelings and consequently find it difficult to "get the feelings out." Additionally, individuals in each of these settings may have a long history of participation in talk therapy yet still may not have accessed more deep-set emotions or issues. These buried or "stuffed down" emotions lend themselves well to accessing the unconscious indirectly, through the *back door*. Some of the metaphors that I have found useful in the clinical art therapy group setting include drawing oneself as an animal, tree, flower, a musical instrument, or a toy. Other metaphorical applications include mask-making for the inner and outer self, the house as a metaphor for the emotional body, the vessel or vase as a metaphor for body, and the seasons as a metaphor for change in one's life.

One particular intervention I have found to be effective in my practice has been the directive, "draw your body as a vessel." In the single class offering titled, "Body as Vessel" choices of vases of varying sizes, shapes, and colors are set up as still lifes. Participants can choose to draw one of these or to draw one from their imagination. They may or may not choose to paint something inside the vessel such as flowers, twigs, water, or stones in the vessel. Innovation, creativity, and abstraction are encouraged. They may choose to carefully duplicate the reflections on the vase, the colors, or the folds in the draped tablecloth or to create a wildly abstract piece. As in most art therapy exercises, there is no right or wrong way to carry out the completion of the directive.

Discussion is centered on looking closely at the vessel. "What is inside of your vessel right now?" "Describe the inside or outside of your vessel as you see it." "Describe the inside or outside of your vase as you feel that others see it." A close look is taken at the painting qualities of light, line, shape, form, color, shade, and hue. Referral is constantly made back to the artwork by posing leading questions or statements such as "…what do *you* see; you, the artmaker…" (Betensky 1995, p. 17), or "I wonder…" It is not unusual for people to be surprised by what they perceive to be down inside their vessel. The responses may range widely from blackness, fog, dirty water, light, ice, trash, roots, and nothingness to descriptive words such as hope, joy, peace, fear The vase may appear as new, shiny, cracked, worn, whimsical, ready to explode, cherished, and on. These descriptors are then used in the group setting to allow group members and the facilitator to assist the creator in making sense or bringing clarity to feelings. As always, the group member also has the option to simply sit with the creation with no response, allowing the image to speak silently.

4.4.6 The Role of Journaling and Poetry in Art Therapy

Like art-making, journaling and poetry often become lost arts as we become adults. It is fairly common for a new group participant to say that they are not comfortable with drawing because one of their early school teachers or professors commented critically about something they created many years earlier. Likewise, some adults may feel they are not capable of being creative when it comes to writing out their thoughts and dreams and may be even more intimidated by poetry. They may feel that if it is not a revised and edited product or does not have a precise rhyming or meter pattern, it is not a good example and therefore unacceptable or unshareable. Yet both anecdotal studies and research have shown that poetry and journal writing can be effective methods to cope with major illnesses and trauma (DeSalvo 1999; Fox 1997). Letting go of preconceived notions of what the artwork, the writing or poetry should look or sound like is an important part of the process of therapeutic expression. Hieb (2005) stressed the importance of using art-journaling, a combination of art and writing as a way to utilize the creative process of journaling to give voice to the authentic self. According to Hieb, this creative combination, making use of both process and product, can be a powerful way to discern and explore spirituality and other life issues.

In art therapy group series classes such as "The Altered Book" class described in this chapter it is the expectation that group members will make use of journaling and poetry assignments to enhance understanding of the artwork created. This helps to explore emotions which may arise as a result of creating and processing the artwork. In addition to time spent on journaling in class, participants are encouraged to spend time at home reflecting further on their work. It is recommended that they use the journals provided as a safe place to record and process emotions that may come forth during the week. While group members may bring something back for further discussion, it is important that they journal for themselves and not with intent to share as writing for a perceived audience can potentially skew free expression around their emotions. Fox (1997) described how poetry can be used to explore life's complexities and mysteries by allowing the blank paper to "accept our deepest pain—thus releasing it so that healing can eventually follow" (p. 244). Similar to the way Levine (2003) described art-making, Fox stated that poetry could also ignite the fires of creativity transforming the individual in the process. Whether making use of metaphor in poem writing, using journaling to process artwork or writing down raw feelings, writing can enhance the art therapy process and also be a powerful way to awaken or reawaken creativity.

The combination of art and journal-writing such as illustrated journaling or creative journaling has become increasingly popular, and there are many resources available to both the professional and the layman. Art therapist, Lucia Capacchione (2001) was a pioneer in the field of combining the two artistic forms to provide a powerful format to document the process of healing or becoming whole. While this combination may at times seem to be counterintuitive to art therapy, particularly to some who may posit that the use of writing may stifle the creative "right brain" process, if correctly introduced as a natural extension of the artwork, it can be part of the flow of creativity. Creative writing can thus continue to make use of imagery in the brain even though written words are not generally considered to be part of the imagery process. Group participants in art therapy groups I have facilitated frequently comment on how surprised they are at what they have written or drawn in their journals after creating artwork and wonder, "Where did that come from?" This acknowledgment can also serve to reinforce what was discovered as a result of the process.

Fox (1997) referred to muses when discussing the origin of artwork or creative writing. Allowing the muse to speak through artwork or writing can open the doors to processing things that might otherwise remain dormant or stuffed down. (McNiff 2004) referred to making use of images or artwork as angels to carry a message to the creator of the work. A dialogue would then be carried out between the angel and the creator as the image or artwork is reflected upon. In this use of active imagination, the artwork would not be talked about, but would be talked *with*, as the artwork would also have a voice. Similarly, Capacchione (2001) encouraged dialogue between the image or the writing and the artist or the author. She also encouraged switching between the dominant and non-dominant hand when writing or drawing to encourage this type of dialogue. Capacchione's method makes use of the right brain, left brain theory wherein the non-dominant hand "speaks" for the right side of the brain, or the visual spatial side which accesses emotion and intuition, and the dominant hand "speaks" for the left side of the brain or the more analytical side. According to her research, this writing or drawing method allows the writers or artists to tap into the body's wisdom so that they can then dialogue with their inner self (Capacchione).

4.5 Altered Books/Altered Lives: A Five-Week Series

When individuals are diagnosed with cancer, their life path often suddenly looks very different to them. Immersed in medical appointments, research about their diagnosis, treatment and insurance, work and financial issues, they often lose sight of the bigger picture of their life, focusing almost entirely on the tasks at hand to the exclusion of their "normal" lives. It is necessary then for them to begin to re-establish a "new normal" to proceed forward (Schmitt and Harding 2011). One art therapy intervention I have found to be effective in working toward this goal is the five-week "Altered Book" series. I developed and facilitated this series for cancer survivors, to assist participants in viewing their life stories and how they have been altered as a result of the experience of having cancer. The therapeutic art exercises around the theme of their life stories were rich with metaphor as they viewed how their life unfolded and changed in unexpected ways.

Re-purposed children's board books with five to seven double-spread pages were used as the primary canvas for the art exercises each week with additional art or writing exercises created outside the book format. While the re-purposed books were a common denominator, it was important to allow freedom for each individual to be able to expand beyond the page if necessary. Their creative process made use of personal stories, line, shape, color, poetry, quotes, music lyrics, and more, as well as the addition of meaningful personal items and images. The addition of early personal photos and meaningful connections enhanced the creative process. Strength building and journaling exercises were embedded into the art therapy each week, and homework was encouraged.

During the first week's session, the books were carefully sanded down and painted with gesso to provide a backdrop for their stories. Words or images from the book's contents were often left revealed to be incorporated into the work later. Participants were asked to bring in a childhood photo for the first week's class to create a starting point for their journey. These were shared as icebreakers at the first session. After preparing the book, the first exercise, "Once Upon a Time…" was to draw or paint what they wanted to be when they grew up. This small drawing with colored pencils was saved so that it could be applied to the book at a later date. After the image was created, we then discussed what strength or trait they would need to go into that field or career. We discussed how it was likely that they may inherently have this strength or characteristic, and if so, how they have used or might use this trait to deal with their diagnosis or treatment. For instance, a participant from a past series illustrated how she wanted to become a firefighter when she grew up and that she chose courage as her strength. Her journaling exercise focused on how she used courage in her everyday life. She then shared how she had to be courageous through her treatment and also on a daily basis as she dealt with the "new normal."

Another individual chose the word spirit as one of her strengths (see Fig. 4.1) using a collaged image of a horse to illustrate this in her book. As coping skills and meditations were accessed each week, these found their way into the books. A double page spread (see Fig. 4.2) on calmness created by using overlaid raspberry papers is an example of illustrating the coping skill of meditation and appears to exude a sense of calmness.

Fig. 4.1 "Spirit" by Cheryl

Fig. 4.2 "Calm" by Chris

Each week a warm-up art therapy exercise was completed and then processed prior to working on the altered book. The second session addressed "letting go." Participants were asked to create a watercolor depicting something they needed to let go of or find a new way of doing as a result of their current state of health related to their diagnosis. They were then asked to cut out or in some way alter part of the watercolor to make use of in their books as a way of illustrating the act of viewing the life change of a diagnosis or treatment from a different perspective. In each series, the participants' creative responses to this task have varied widely, from repainting; washing away the paint; writing on a scrap of the painting; cutting and pasting or reworking the paper in some manner. The third session made use of Scrabble ™ letters. As a group, participants were asked to create connecting words with the letter tiles spelling out some of the negative words that they thought of around diagnosis or treatment. Over the course of three Altered Book series that have been offered, words that consistently appeared included pain, fatigue, fear, recurrence, tired, anger, and sad. Time was provided to journal on these topics and discussion followed. Part two of this exercise was to rearrange or alter the words into positive or coping words. These were sometimes more difficult to quickly access. Common words in this word puzzle included strength, humor, here-now, optimism, calm, and joy. Participants were again encouraged to journal about words they resonated with and then discussion took place as a group. Further journaling was encouraged as homework. Exercises in remaining sessions included "ways we nurture ourselves" collages and fairytale metaphors. Participants often created extra pockets or extensions to contain more aspects of their story. Much time was spent making decisions on media choices, color and style selections, and individual themes. They were encouraged to tell their unique story using whatever best fit their themes. Group members were also encouraged to carry themes they were exploring beyond the art room to find creative and metaphorical applications in their everyday lives. This transfer of awareness beyond active participation in writing/illustrating and reframing their own stories was helpful in assisting participants to feel empowered as evidenced by their feedback. Anecdotal feedback from some participants has also indicated that the effects have been long-lasting.

In many therapeutic groups, there tends to be an upswing of stress and anxiety toward the middle of the group sessions (Yalom 1995). It is often at this point, as the group becomes more cohesive and the environment feels like a safe place to share, that a crisis of sorts occurs when participants realize they are not sure where their story is going or what they want it to look like. Positivity and strength building exercises are important to incorporate at this time. Therapeutic guidance is also important to ensure that group members are able to get over this hump. As they share at deeper levels, they are able to move beyond the individual pages, seeing their lives as unique stories, “making-meaning” through art-making. The flow of creativity is strengthened additionally by mutual support of the members as camaraderie is developed. Group members also support each other by offering images which support one another’s themes, sharing painting techniques or creative tips with one another or bringing in articles or images from home that they think may be meaningful to another.

During the last week of each Altered Book series, individuals shared their book as a whole along with the insights they discovered. Laughter often mingled with tears in each of the final sessions as they looked back over the journey of their book-making. Over the course of several years, a number of group participants returned to share that their book was precious to them and was of great help to them in navigating the cancer journey. Additionally, several have continued to create altered books and visual journals as a way to access their deeper thoughts and express themselves. Halprin (2003) stated, “When art expression and felt experience truly meet, or when an individual’s art fully reflects some important part of her psyche and story, she herself is moved and changed by it” (p. 94).

4.6 Re-awakening Creativity Through Art: A Half-Day Workshop—Part One

The two half-day art workshops created around re-awakening creativity served a different purpose than the five-week series. Whereas the series classes were designed to assist participants in taking a deep look at the emotions around their diagnosis and treatment, the half-day workshops were designed as a creative outlet and to provide more of a positive distraction from day-to-day concerns. Similar to the Altered Book series, however, the workshops also provided creative tools to deal with emotions and difficulties due to a diagnosis. Consequently, in addition to the processing of their artwork and the thematic exercises, participants were able to take away strength-building and coping skills. These programs were designed to provide the opportunity for participants to leave their worries at the door and get away from their concerns for a few hours.

The artwork created in such a group is processed at a lighter level so that participants are able to go home in a positive state. Given the time frame and setting, it would not be appropriate to open up deeper levels of emotion without the safety of a continuous group. The connections made with other survivors and caregivers are often invaluable as newcomers realize they are not traveling the cancer journey alone. At times, these connections alone can alter the course of a newly diagnosed person as they find support from someone who understands how they are feeling. It can also provide a feeling of altruism and a sense of giving back for those who have navigated the journey a bit longer.

The two creativity workshops were created to empower participants to make use of creativity to express themselves beyond visual art by incorporating storytelling, theater, poetry, music, and dance into the sessions. Previous to this workshop, many attendees had only attended visual workshops although some had also made use of other types of workshops provided in this setting. Others had never attended any programs and were newcomers to the programs.

As an introductory exercise, participants were asked to create a small sketch of themselves using crayons to introduce themselves to the group. The four tables of attendees were given different directives as follows: "Draw yourself as a kitchen appliance," "Draw yourself as a toy," "Draw yourself as a musical instrument," and "Draw yourself as an animal." Sharing these drawings served as icebreakers, set a light tone for the day, and developed anticipation for the rest of the workshop. A visiting professor of creativity had been invited to provide the next art activity along with a short chat on creativity. Participants were asked to create a vacation scene or memory using only a stick of gum, two toothpicks, and a 3 × 5 card. There was a momentary hesitation on their faces, while they thought through the task before them. Within moments, however, they had recovered and creative works quickly ensued. The room was silent as they each set about creating their own mini-worlds. Within twenty-minute mini camping scenes complete with campfire, beach scenes with reclining chairs, tiki huts, sun umbrellas, and other creative applications appeared. Once the creative "juices" began flowing, there was no end to what was possible. As participants shared their creations, there was laughter and awe at the many variations within the group. This provided a feeling of camaraderie within the group; thus, the tone was set for the morning.

The primary activity of the day was very different from any of the group art activities that some of the participants had previously taken part in so there was a bit of nervousness as they realized that they would be creating an improvisational piece within a group instead of the individual work that they were accustomed to doing. Five themed laundry baskets were filled with props prior to the workshop and were covered so that the contents could not be seen. Each table group was asked to pick a numbered basket to use for their performance. After looking through its contents, the groups could then decide whether they wanted to keep the basket or trade it in for a different one. The themes were broad-ranging, and "assignments" or tasks on each card related to the medical community in which the workshop were held.

Groups were given forty-five minutes to divide up into different work areas and create a presentation to be shared with the entire group of attendees when they returned to the main workspace. Singing, poetry, dance, meditations, or artworks were encouraged. Props ranged from clothesline, clothespins, soup kettles, fabric, ribbons, baskets, sunglasses, Styrofoam™ stars, quotes, silk scarves, parachutes, stuffed animals, musical instruments, art supplies, cardboard for backdrops, and more. The presentations varied widely in use of materials, interaction with their audience, and style of presentation.

One group created an ephemeral floating "sea" of survivors, which flowed into the room led by a masked muse or mermaid draped in a gown fashioned from a tablecloth. The "sea" was created using a netted parachute which flowed in and out of the small group members' arms and hands as they moved through the audience of other attendees, gently beckoning each person to become part of the creative process. Each onlooker was bestowed with a starfish emblazoned with the word "flow" as several quotes on the flow process were read by their narrator. Other presentations were equally as creative, from a festive song and dance about creating the perfect healthy pot of soup to an all pink style show and skit with sequined bikinis made from ribbon and stylish pink purses made from baskets. Problem-solving skills were used to come up with ways to incorporate their group members as well as the audience.

One individual chose to take a themed basket by herself and quickly went to work. Her laundry basket was actually themed around laundry and contained T-shirts with the word survivor written on them. She created a soliloquy and a poem she had written about survivorship. She utilized the clothesline, clothesbasket, and T-shirts from the props and literally the shirt off her back as she hung a combination of back and white shirts up to demonstrate how a percentage of women get breast cancer in their lifetime. This final piece mesmerized the group as she captured both the reason (having a cancer diagnosis) they had all attended such a workshop, but also extended a feeling of gratitude in poem for the physicians and nurses who treated her. At the end of her inspirational presentation, each person was presented a clothespin she had inscribed with the title and the date of the workshop written on it as a way to savor the day in the future. Group participants felt certain she had spent hours prior to the performance, yet she had simply gotten into the flow of the day and allowed her creativity to come forth. The power of creativity to inspire, to heal, and to provide a sense of connection was evident in each of the day's amazing works. For many weeks afterward, notes and other correspondence referenced this day as meaningful to those who had attended.

As the last activity of the day, the group returned to their seats to create "creativity jars" for themselves. Each participant was provided a quart-sized decanter jar which they collaged using magazine images and other materials (see Figs. 4.3 and 4.4). Multi-colored strips with various exercises designed to view the world creatively were provided as well as blank slips on which they could write their own ideas. These were to be used as inspirational jars to pull from when they desired to do something creative and needed an extra boost.

Fig. 4.3 "Creativity Jar" by Donna

Fig. 4.4 Top of "Creativity Jar" by Donna

4.7 Re-awakening Creativity Through Art: A Half-Day Workshop Part Two

The second half-day workshop was focused on the theme of reawakening creativity using vacations or "stay-cations" as the theme. The room was decorated with travel agency posters and featured various vacation destinations. Recognizing that some participants may not have been on a vacation for some time due to financial constraints or to being in treatment, the day was designed a "getaway" to various destinations. Props and supplies included art supplies for beginning and closing art exercises and five themed laundry baskets containing materials for each group to create an interactive expressive arts presentation. Large cardboard pieces were provided to create backdrops for the presentations if the groups chose to do so.

Group participants were first invited to create a colored pencil drawing of themselves on a favorite vacation. This could be someplace they had recently traveled, to a local park or nearby destination or even someplace they had travelled to as a child that held special memories. This activity incorporated the savoring technique both as they drew and as they used these pieces as a way of introducing themselves to the group. Group members thoughtfully shared in a way that allowed others to also sense some of the "magic" of the trip. Like the toothpick and index card exercise in the workshop previously, they were easily able to access something that was restful, relaxing, or personally meaningful in some way. In addition to being able to reminisce about their own vacation or getaway, as they shared their artwork, they could relate to each other as they recalled meaningful experiences, sights, smells, and sounds they themselves had taken to similar places. The "vacation" destinations that were offered in themed baskets included a beach package, a mountain climbing expedition, a jungle expedition, and a forest hiking or camping trip. Props were provided for each area in various stations throughout several rooms. Participants could choose what destination they wanted to explore and join that group to create a presentation or skit within an hour to bring back to the group as a whole. A music therapy intern was also on-site to provide instruments and offer accompaniment or recorded music on demand for anyone who chose to incorporate music into their skit or presentation. Presenters were encouraged to involve their audience which consisted of the attendees within the other art groups, in the process so that they each had the opportunity to experience all of the vacation settings.

The presentations varied from an invitation to enjoy sights, smell, tastes, and sounds of the beach, to participating in a campfire song and dance, and also included poetry and participatory storytelling and singing. During the various interactive performances group, members were encouraged to roast Styrofoam marshmallows at the campfire, eat bananas in the jungle, play in the sand, and experience the excitement of climbing a mountain via storytelling. They made use of beach clothes, saris, safari hats, site-specific foods, puppets, sunglasses, boots, and knitted caps depending on the vacation site. Costumes were crafted from tablecloths, plastic, masks, ribbon, and other materials. Participants laughed and

Fig. 4.5 "Beach Vacation" Basket

Fig. 4.6 "Beach Vacation"

joked with one another, while they constructed costumes, backdrops, and songs or dances. Camaraderie developed among individuals in the each group and also spread as they each attended the others' presentations (Figs. 4.5 and 4.6).

One individual chose the beach-themed basket and decided to create a scene on her own since no one else had chosen the beach theme. She quickly designed a mermaid type costume from thrift store sundresses, sunglasses, straw hats, and netting. This participant chose to make use of nearly all of the beach props so that she could invite each of the other members into a full sensory experience: hearing, seeing, feeling, smelling, and tasting. She shared a poem (see Table 4.2) which she

Table 4.2 Beach blessings by D. Gale

Find peace at the beach. Dig your toes in the sand. Toss your cares in the waves. Hold the starfish in your hand. Feel the sun on your face. Smell the salt in the air. Taste the orange on your tongue. Enjoy the breeze blowing your hair. Just relax and let go. Sift the sand, white as snow. Take a straw; have a sip. In healing waters take a dip. Close your eyes. Hear the surf. At the shoreline, Give joy birth.

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had quickly crafted around her theme and used it as an invitation for attendees to participate. Participants were invited to don sunglasses or hats, sit or lay down on the beach towels, sift sand through their fingers, make sandcastles, touch the starfish shells, smell and taste the orange slices, hear the sounds of the waves in the background, and play by throwing the beach ball back and forth. As the morning sunshine poured through the full length windows of the activity room, a spirit of playfulness prevailed transforming the space into a sandy beach.

The group who led the walk through the forest incorporated a meditative reflective dialogue they had created around the richness the woods had to offer. One of this group's members, draped in tablecloths and a woodlands mask became the muse of the forest, inviting others to savor the beauties of the forest as she encouraged people to reconnect with the earth using her reminiscing skills to set the mood. Styrofoam™ balls became marshmallows on sticks to be roasted over a construction paper fire and were shared with the audience along with chocolate on cardboard graham crackers representing S'mores. Participants were invited to join in campfire song and dance.

Another individual member decided to embrace the mountain theme by herself since she was drawn to the subject matter, and no one else chose that basket. Using the art of storytelling and equipped with a walking stick, vest, and hiking boots, she led the group on a mountain climbing expedition in China. Participants could almost feel the chilly air and sense the trepidation of peering down over the mountaintop, the empowerment of having scaled to the top of the mountain as they "tromped" along with the leader while seated in a semi-circle around the cardboard mountain. Trail mix and warm hats were offered to the viewers. Additionally, books on navigating the cancer journey using the theme of climbing a mountain were given out to participants as a way to further make use of this metaphor in their own lives beyond the workshop.

The jungle scene was colorfully crafted from jungle puppets and costumes with a colorful tropical backdrop of ferns, cardboard trees, tropical bird photos, ropes, and banana bunches. Jungle-themed songs were shared and sung with the group. Safari leaders, monkeys, parrots, and elephants paraded through the room. Lots of laughter emanated from this group during the crafting of the scenery, planning of the dialogue, and in the interaction with their audience. In this presentation, as in the others, group members supported one another in their role-playing

When all of the group participants gathered back into the main room, they were asked to paint and self-address watercolor postcards to themselves which would be sent to them at a later date. Encouraging messages were written on the postcards as reminders to savor the memories. They each shared their postcards along with their thoughts about the day. Participants then gathered on the "beach" where they sang a parting song accompanied by the music therapy intern on her guitar. The postcards were mailed back to participants along with a homework exercise derived from Bryant and Veroff's (2007) "daily vacation exercises" (p. 211).

4.8 Summary

This chapter sought to illustrate how the creative innovations within art therapy sessions for cancer survivors could empower individuals to continue to use, not only the insights gathered through art therapy exercises, but also to identify and apply their inherent strengths and their own creativity to daily living. McNiff (2004) contended that as current models of healthcare promote a more inclusive, comprehensive view which may address emotional health and spiritual health as well as physical needs, both art and spirituality practices deserve a closer look. Moon (2010) advocated that art therapists make use of the creativity inherent in the profession to provide a wide range of creative experiences beyond paint and canvas as vehicles for transformation and healing. As Wilkinson and Chilton (2013) stated, the combination of art therapy with positive psychology can empower individuals, moving individuals beyond merely surviving to a state of thriving. They further suggested that art therapy research focused on this combination could add to both fields, increasing our understanding of how creativity can impact well-being. The programs presented in this chapter were an effort to demonstrate the endless possibilities that can open up for both the patient and the therapist when thinking "outside the box". In closing, I am reminded of a youthful eighty-three-year-old gentleman with a terminal diagnosis who attended a therapeutic nature painting session I facilitated. When sharing his painting of an acorn with the group, he stated, "When I look at my painting, I see possibilities." And isn't that what art therapy, creativity, and life itself is all about?

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Chapter 5
Creativity in Theoretical Physics

Robert J. Perry

Abstract Creativity in theoretical physics is illustrated by breakthroughs ranging from the creation of the calculus by Newton to the invention of the neutrino by Pauli. The natural language of science is mathematics. Sometimes, physicists must expand this language, and usually, they take clues from it and its severe constraints.

Keywords Theoretical physics · Creativity · Mathematics · Physics education

5.1 Introduction

> **Creative**
>
> - **adjective** involving the use of the imagination or original ideas in order to create something
>
> —Oxford English Dictionary

I have no expertise on creativity. When asked by Dr. Charyton to speak to her class about creativity in the physical sciences, I was not sure how to approach the subject.

My first step was to narrow the topic, focusing on something I do know, theoretical physics. My second step was to consult some of the great minds in theoretical physics, starting with Richard Feynman and Albert Einstein. From Feynman, "I believe that a scientist looking at nonscientific problems is just as dumb as the next guy." This was not immediately reassuring, so I found another Feynman quote, "Since then I never pay attention to anything by 'experts,' I calculate everything by myself."

We often discuss the need to teach our students not only the subject matter of physics but also, more importantly, how to think like a physicist. Physicists use paradigms, examples stripped of everything but what is essential, to explore limitations in old theories and develop new theories. I knew my principal examples would illustrate

R.J. Perry (✉)
Physics Department, The Ohio State University, 191 W. Woodruff Ave.,
Columbus, OH 43210, USA
e-mail: perry.6@osu.edu

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paradigm shifts in theoretical physics. I wanted to find creativity in theoretical physics and then see what I might learn about how it works. Finding out what things are and how they work is a prototypical problem in physics or any science. This reassured me.

At this point, I realized that I had already stumbled upon the principal example of creativity in science, the scientific process itself. I oversimplify that process as follows: (i) observe and classify phenomena, (ii) make up a theory, and (iii) test the theory. If the theory fails, loop back to (ii) and if that fails loop all the way back to (i). Unfortunately, every test relies on measurement and every measurement requires a theory for how a measurement device works. Scientific progress can stall when the theory we want to test underlies our theory of how measurements work. Progress then requires a paradigm shift, a rethinking of the very enterprise itself, and creativity can be found here if anywhere.

A naive description of the scientific process would leave out any explicit discussion of creativity. Scientists might be said to *discover* natural truths, but the nature of their activity seemingly requires them to not create truths. We expect that an intelligent alien species that evolves in conditions similar to ours will have "the same" mathematics and laws of physics that we have *discovered*. Where is there any need for creativity?

Needing further inspiration, I turned to Einstein, "The secret to creativity is knowing how to hide your sources." It was not immediately clear to me that this is useful, but it does point to the fact that creativity does not exist in a vacuum. Groundwork must be laid. The groundwork behind the scientific method (e.g., the creation of speech) was largely laid by the time of the Greeks, but it was an additional 2,000 years before Galileo would move beyond Aristotle's physics, as I discuss further below. I will give a drastically oversimplified account of the leap made by Galileo, the sort of account physicists often give of their own activity, one that ignores most of the real story in order to focus on what they think is essential. The hero of the story profits somewhat.

Einstein also said, "The only thing that interferes with my learning is my education." Again, not immediately clear how this is useful, but it points to one of the biggest barriers to scientific progress, what we think we already understand. The biggest barriers to scientific progress are built with what we "know."

"Creativity is a type of learning process where the teacher and pupil are located in the same individual," according to Arthur Koestler. This gave me my best hint on how to proceed.

My next step was to look at what we teach our students in introductory physics classes and think about the origins of the most fundamental aspects of physical theories. We start with classical mechanics, the study of objects in motion, which gave birth to theoretical physics, and my first theme.

5.2 Focus on the Essential to Reveal the Universal

Having had a liberal arts education, I know how amazingly difficult it was for physicists to even figure out what they needed to talk about in order to invent a science of mechanical motion. Position, velocity, and acceleration were obviously relevant, but these concepts underwent drastic evolution between Aristotle and Newton.

According to Aristotle (350 B.C.E.; Aristotle 1962), objects in motion in the heavens tend to stay in motion, but objects in motion on earth tend to come to rest. Two laws, lacking almost all of the detail that would eventually characterize physical theories, for two supposedly different types of phenomena. It is relatively easy to demonstrate Aristotle's law for motion on earth in the classroom. Throw any object. Wait a bit. It will come to rest. It is not that Aristotle is wrong, but he missed what is essential and failed to discover what Newton would show is universal, one set of laws for all motion in the heavens and on earth.

After 2,000 years of limited progress,[1] Galileo (1632, 1953) made several critical breakthroughs. Well known is his progress in understanding motion in the heavens, accepting the Copernican revolution (Copernicus 1543, 1959) and removing earth from the center of the universe, realizing that the earth orbits the sun and that heavenly motion is the daily rotation of the earth coupled to its annual transit around the sun.[2]

Of even greater significance in unifying heavenly motion with motion of objects on earth was Galileo's observation of the oscillatory motion of a swinging pendulum. He made an intuitive leap while watching this motion and realized that Aristotle was wrong, that objects on earth do not naturally come to rest. The *natural* motion of all objects, unless acted on by an external force, is to continue in motion. This would become Newton's first law of motion. But the appropriate language with which to state laws of physics needed significant development. True creativity was required, and another genius was needed.

In Fig. 5.1, a typical figure showing the motion of a projectile under the influence of gravity, I display a panoply of creativity. The Cartesian (Descartes 1637, 2001) axes, the trajectory, the vectors representing the gravitational force, and velocity at three points, all are mathematical creations. This figure displays the same sort of motion Aristotle intended to explain in his physics, but it goes far beyond the sort of qualitative description that limited his entire enterprise.

The only physical object displayed in the figure is the projectile, and it is represented by a featureless dot, as if the shape, size, color, and almost all properties of the object other than its position do not matter. This is because in most situations, *to a very good approximation*, none of these properties matter. But even the motion displayed is an idealization, a perfect parabola, the solution our theory gives when air friction and many small effects are ignored. Realizing that the complicated details of all actual motion should be put in as corrections to this idealized motion made systematic progress in physics possible.

The Cartesian *x–y* axes are familiar to all students. What may not have been emphasized in their education is that such axes exist nowhere in nature. There are no straight lines in nature. They are not to be discovered anywhere. These axes provide a critical tool for the development of mathematical laws of motion and

[1] Ptolemy is an exception that proves the rule. His remarkably accurate tables for planetary motion were a tour-de-force of curve fitting. His rules of motion simply dictated using layers of circular motion, epicycles. His epicycles must be routinely updated, and each new solar system requires its own precisely tuned epicycles. It might seem universal if you only know about circles but it is not.

[2] This was really a rediscovery, as it was even known by some Greeks.

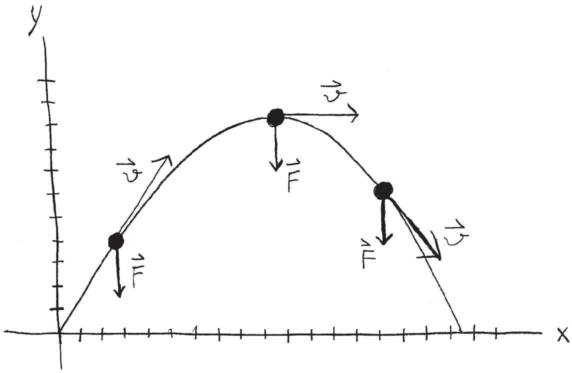

Fig. 5.1 Projectile motion with Cartesian axes. The constant gravitational force and changing velocity are displayed at three points along the trajectory

provide an ideal toward which experimentalists can work. In another brilliant observation, Galileo observed that mathematics is the natural language of science, accelerating the employment of a huge range of mathematical creativity in the advancement of science.

In rectilinear coordinates, each position in three-dimensional space is assigned a triplet of numbers, the x-, y-, and z-coordinates. Geometry and algebra are married, and the groundwork is laid for Newton (Newton 1687; Newton 1833) to provide precise mathematical laws of motion. Velocity and acceleration can now be given precise mathematical definitions. Velocity is the slope of a curve displaying position as a function of time. Acceleration is the slope of the curve showing velocity as a function of time.

Descartes' coordinates allow us to develop a precise numerical definition of the slope of a function. For simplicity, I consider motion in one dimension, which for a "point particle"[3] is completely given by $x(t)$, the position as a function of time. The velocity can be precisely defined:

$$v(t) = \frac{\mathrm{d}x}{\mathrm{d}t} \equiv \lim_{\mathrm{d}t \to 0} \frac{x(t + \mathrm{d}t) - x(t)}{\mathrm{d}t} \tag{5.1}$$

Velocity, $v(t)$, is the slope of the position curve, its rate of change. This is a limit, the difference between two positions at slightly different time, t and $t + \mathrm{d}t$, as $\mathrm{d}t$ is taken to zero. We assume that even though we never observe any actual object's trajectory with infinite precision, its position is perfectly determined, its velocity is perfectly determined, etc.

In fact, we can never resolve actual motion with the infinite precision required by Newton's definition of the derivative. We cannot take two "snapshots" that are separated by an arbitrarily small amount of time. For example, most movies do not resolve time much better 1/100 s per frame. Further, quantum mechanics, which we will encounter below, implies that it is physically impossible to watch the

[3] It took Newton several years to define the center of mass, a precise definition for the point displayed in Fig. 5.1.

motion of any object with this precision without first disturbing the objects motion and eventually, far before dt reaches zero, destroying the object completely. The mathematics is too precise!

One of the most important operating hypotheses in physics is that **the details do not matter**.[4] If we want to describe the motion of a baseball, or a satellite, we do not need to keep track of its atomic constituents. Our mathematical languages insert the wrong details, adding infinitely precise details that are simply not there. We then drastically oversimplify the detailed structure of objects; for example, our baseball is first modeled as a uniformly dense sphere of amorphous matter. We solve our equations as if they are infinitely precise, but we only believe a small number[5] of "significant" figures in our solutions.

> To those who do not know mathematics it is difficult to get across a real feeling as to the beauty, the deepest beauty, of nature… If you want to learn about nature, to appreciate nature, it is necessary to understand the language that she speaks in.
>
> —Richard Feynman

> As far as the laws of mathematics refer to reality, they are not certain, as far as they are certain, they do not refer to reality.
>
> —Albert Einstein

In three dimensions, where we apparently live, position, $\mathbf{x}$, velocity, $\mathbf{v}$, and acceleration (the rate at which velocity changes), $\mathbf{a}$, are "vectors." They have a magnitude and a direction, indicated by using boldface fonts or putting an arrow above the letter. For position, the magnitude is distance from the origin of the coordinate system and the direction is from the origin toward the object. For velocity, the magnitude is the speed of motion and the direction is the direction of motion.

Newton's first law of motion is that objects that are not acted on by a force have a constant velocity:

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{v} = 0, \tag{5.2}$$

when $\mathbf{F} = 0$. Forces also have magnitude and direction. You do not simply push; you push with a certain amount of force and in a certain direction. This must be perfectly reflected by *the math*.

Newton's second law of motion is that force determines the rate at which velocity changes:

$$m\boldsymbol{a} = m\frac{\mathrm{d}}{\mathrm{d}t}\boldsymbol{v} = \boldsymbol{F}. \tag{5.3}$$

You do not need to solve these equations to appreciate their power. Given the initial positions and velocities of some objects (e.g., planets) and the forces between them (e.g., gravity), Newton's second law predicts their positions for all time. If there are very many objects, a supercomputer is helpful.

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[4] Until they do. Eventually, we get to the details.

[5] Very few universal constants are known to twenty significant figures.

I like to start every subject I teach with a brief discussion of why I believe "exact science" is an oxymoron. I like to warn students that none of the laws of physics we study are more than approximations with a limited domain of applicability. Newton's laws are wrong. They break down completely when velocities approach the speed of light, c, and when objects are of atomic or smaller scale.

5.3 Follow the Equations

Maxwell's (1863, 1865) equations for electromagnetism were reliably established when Einstein was a student, but they contain an apparent flaw. They contain the speed of light, c, as a constant. But speeds are not constants. If I watch someone throw a ball on a passing train, I see the ball move with a speed that includes the train's motion, but someone on the train sees a different speed.

To understand this, many physicists assumed that light is a wave in an actual medium, like waves in water. In this case, the medium provides a preferred rest frame and the speed in Maxwell's equations is what is measured as speed relative to this fixed medium. This is not an elegant solution, positing the existence of a substance that has never been observed. It is also incorrect, assuming that, if you watch someone on a moving train turn on a flashlight, you will measure the speed of light to be a bit different than when you turn it on yourself.

Einstein (1905a, b) assumed Newton was wrong, that Maxwell's equations are precisely true and everyone measures the same speed for light. This leads to an apparent paradox. How can I get the same speed for an object's motion as someone moving on a train?

Start with the definition of velocity, again in one dimension for simplicity,

$$v(t) = \frac{\mathrm{d}x}{\mathrm{d}t} \equiv \lim_{\mathrm{d}t \to 0} \frac{x(t + \mathrm{d}t) - x(t)}{\mathrm{d}t}. \tag{5.4}$$

To measure velocity, we each measure two positions and a time difference. But I see the position changing a different amount because of the train's motion. For example, if someone on the train throws a ball opposite the direction the train is moving, I might see it stop and start to fall, with zero speed right after it is released. As it falls, a wall of the train rushes toward it. But someone on the train is measuring positions using a coordinate system moving with them on the train, and they see the ball moving relative to the train, rushing toward the stationary wall as it falls. Both observers are right, and we should be able to find equations that precisely determine the relationship between measurements in different *frames of reference*.

Einstein kept the definitions of position, velocity, and acceleration unchanged for an observer at rest, but he argued that observers moving relative to each other are going to have a problem comparing measurements. Lengths, such as $\mathrm{d}x$, are seen to grow smaller as objects move. Clocks measure time intervals, such as $\mathrm{d}t$, and they appear to slow when they move. More confusing, each observer sees the moving clocks used to make measurements in other frames as out of sync. If we look at clocks on a moving train that have been synchronized by observers on the train, we see clocks at the front of the train showing a different time from those at the back. In general, every observer needs two clocks to measure a speed, one at the start and one at the finish of the motion. Time intervals cannot be accurately measured by subtracting readings from two clocks that are out of sync but that is exactly what we see all moving observers do.

If I measure the speed of light with my synchronized clocks and fixed measuring sticks, I get c, just as Maxwell insists. I watch someone on a passing train measure the speed and see them get c, but I see them using slow clocks that are out of sync and meter sticks that are shorter than a meter.

We know the speed of light exactly, 299,792,458 m/s. We know it exactly because in 1983, the meter was redefined to be whatever length is required to get this speed for light. To make measurements that test the laws of physics, we need a theory of measurement and our theory of measurement is rooted in the very laws we need to verify. Newton's laws rely on an implicit theory of how meter sticks and clocks work. Maxwell's equations for electromagnetism were developed assuming this same theory of measurement, but upon further study end up being inconsistent with this theory of measurement. Einstein created a new theory of measurement that is consistent with Maxwell's equations and accepted as a consequence that Newton's equations are incorrect when speeds approach the speed of light. All of this, Einstein realized, was required if we insist that Maxwell's equations are universal, that they are valid in stationary and moving frames of reference, and in every frame, the speed of light is the same.

5.4 Use Analogies to Develop Radically New Equations

The very nature of space and time depends on motion. Newton's equations for the motion of particles are drastically modified by special relativity, but the notion of particles remains firm. Quantum mechanics revolutionizes our notion of particles themselves and introduces further drastic changes to our theory of measurement. Once again, an entirely new way of thinking about and mathematically representing the fundamental concepts employed in physics had to be created.

The Figs. 5.2 and 5.3 illustrate how waves (e.g., waves on the surface of water) behave when passing through slits. In Fig. 5.2, a wave passes through a single slit and diffracts. Particles, on the other hand, simply hit the wall or pass through the slit, moving in a straight line, but waves bend outward after passing through a slit. The narrower the slit, the wider the diffraction. For particles, as the slit narrows, the beam of particles passing straight through the slit is also narrowed. But when we shoot particles through a slit, we actually find the beam widen as the slit narrows, just like waves.

In Fig. 5.3, a wave passes through two nearby slits, producing two waves radiating radially outward from the slits. In some places, peaks from both waves meet,

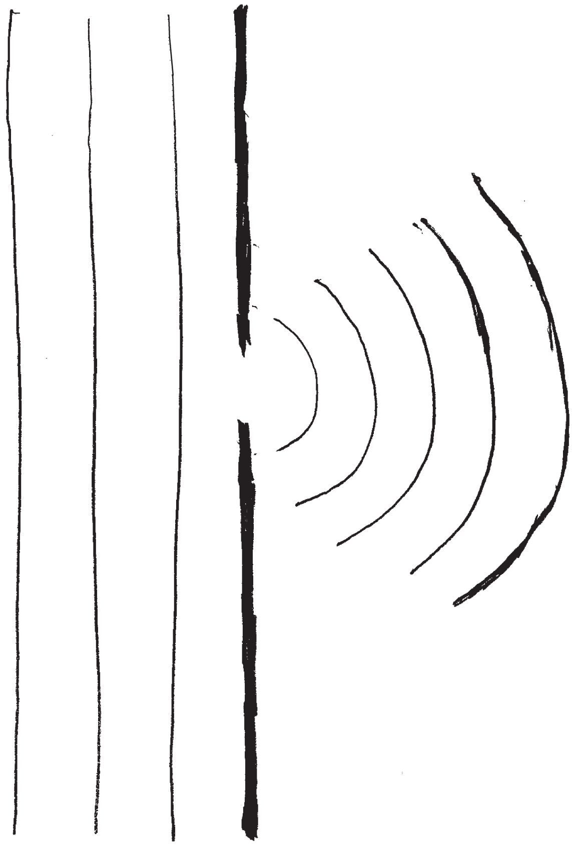

Fig. 5.2 Waves diffract outward after passing through a slit

producing constructive interference; in other places, a peak from one encounters a trough from the other, producing destructive interference. Particles shot through two slits simply fly straight through one slit or the other.

What would happen if we shot a beam of electrons at the slits? Electrons are fundamental particles, so if no force acts on them, they should move in straight lines. If the line happens to pass through the slits, the electron fly straight through. We expect to see two narrow beams, one behind each of the final slits, from electrons that happened to pass through the slit. But that is not what we see.

Let's shoot electrons through one at a time, so that there is no chance of them doing something strange because of the interactions in flight. We place a piece of film behind the slits, so that each time an electron gets through to the film, a tiny dot appears where it hits. But the pattern that emerges over time is not two dots behind the two slits, it is an interference pattern like that waves produce. In some places, many electrons hit, in others none hit.

If we close one of the final slits, the interference pattern disappears and all of the electrons hit behind the open slit. There may be some diffraction, the dot on the film being slightly larger than we would expect from electrons moving in

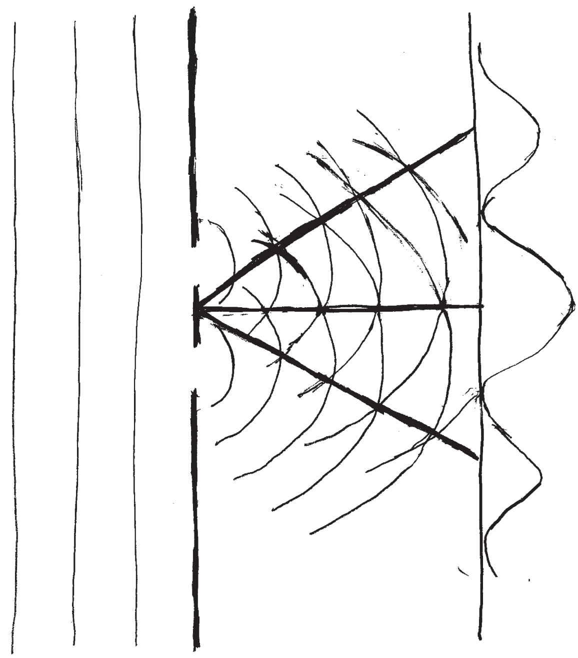

Fig. 5.3 Waves passing through two slits interfere with each other, producing an interference pattern. *Lines* along which peaks from both waves radiate outward are displayed

straight lines, but this is a more subtle phenomenon, a detail. The interference pattern is produced by waves because waves go through both slits. The part of the wave going through the upper slit interferes with the part going through the lower slit. How does an electron go through both slits?

Up to this point, physicists had described the motion of a particle with a position vector, $\mathbf{x}(t)$, as discussed above. But this assumes a particle exists only in one place, like the electrons when they hit the film and produce a dot at a "point." We need a new description of particle motion and new laws of physics for that motion, that account for electrons hitting at points, like particles, but moving like waves.

By this point in the evolution of physics, physicists have started to fully realize just how powerful this math stuff is. Just knowing that we need to find equations became a valuable clue. Let's see, we need a wave equation. I know some wave equations. Let's try them and play around with them if necessary.

Eventually, this line of thought leads to Schrodinger's equation (Schrödinger 1926a, b), the fundamental equation of motion in quantum mechanics. A first step was taken by Einstein (1905c, d), who in his Nobel Prize winning 1905 work on the photoelectric effect showed that light, an electromagnetic wave, sometimes behaves like a large number of particles, photons. He showed how light's wavelike properties, wavelength and frequency, could be related to its particlelike properties, momentum and energy. Over 20 years later, De Broglie (1924a, b) won a Nobel Prize by inverting Einstein's ideas and assigning wavelike properties to particles.

The development of Schrodinger's equation required brilliance, but the real revolution was in how the equation is interpreted and employed. The wave that "describes" an electron's motion is represented by a function of position and time, $\psi(\mathbf{x},t)$. If this were a wave on water, $\psi(\mathbf{x},t)$ might represent the height of the water at position $\mathbf{x}$ and time t. But in quantum mechanics, $\psi(\mathbf{x},t)$ is the *probability amplitude* for finding the particle at position $\mathbf{x}$ and time t. We cannot directly observe the wave function. We cannot predict with any certainty where we will find the electron if we "look." It gives us the probability, $|\psi(\mathbf{x},t)|^2$, of finding an electron at a given position and time but implies that no amount of information about the initial state will enable us to predict a precise position. To paraphrase Einstein, God does indeed play dice with the world.

What exists when the electron is in flight? A pointlike particle does not exist,[6] not in any sense in which we conceive material existence. We have learned that objects persist when we do not directly observe them, in the same form as when we are observing them. This knowledge is literally hardwired into our brains as part of our early learning process. Conceiving of a world in which this basic property of material objects does not hold is creative. We are led to create such a theory by observations, but once again we must re-evaluate the very nature of observation to make progress.

5.5 Sometimes the Equations Are Right, but There is Something Missing

Radioactive decay of nuclei was observed near the end of the nineteenth century and was eventually understood to involve a neutron decaying into a proton plus an electron. But when such reactions were studied in detail, it was found that energy does not seem to be conserved. We know the energy of a neutron at rest from $E = mc^2$, where m is the mass of the neutron. The energy of the proton and electron emitted by the decay of the neutron are similarly known. It was seen that there seem to be a range of final energies, with the entire range being less than the initial energy. It seemed as if energy was not being conserved in this particular type of interaction.

Energy conservation is a consequence of Newton's equations, their relativistic extension and the Schrodinger equation. If energy is not conserved, the fundamental tenets of physics need one more adjustment. Should we change the equations? Or should we assume that energy is always conserved, in which case something must be there after a neutron decays that was not being seen. There is energy missing because *there is a new particle* that had never been seen, which was also being emitted and carrying off some of the neutron's energy.

In 1930, Pauli (1930a, b) proposed the existence of the *neutrino* (a term coined later by Enrico Fermi) to explain this missing energy. To explain why it had never

[6] Unless we look.

been seen, Pauli proposed that it interacts extremely weakly with matter. A new particle and a new interaction, the weak interaction, were proposed to solve a single missing energy problem. Later, physicists would postulate new particles at the drop of a hat, but in 1930, this was still quite radical.

Did Pauli discover the neutrino? It was not actually observed until 1956. Did he invent it? I believe this is another example of creativity in theoretical physics. The creation was the *concepts* of a new particle and new interaction. Their detailed properties would be revealed by further experiments, but the concepts were required to direct the experiments, to figure out where and how to look for neutrinos.

5.6 Conclusion

To summarize, Descartes' creation of coordinate systems and Galileo's insight that motion is "naturally" continuous, that we must find causes whenever velocity is not constant, led to Newton's creation of the calculus with which he could precisely state universal laws of motion.[7] Theoretical physics was, in a sense, created by Newton. Our task is to "find" universal laws that are stated as precisely defined mathematical equations, creating the mathematical language required when it is not already available. An essential part of this task is to precisely relate our equations to observable properties of nature.[8]

Additional study of electromagnetic effects led to new equations for electromagnetic fields that produce electromagnetic forces to be used in Newton's equations. But Maxwell's equations contain the speed of light as a universal constant, which is inconsistent with Newton's equations. This led Einstein to redesign the workings of space and time, the basic mathematical stage on which physical laws are formulated. Newton's laws were not discarded but found to be reasonable approximations to relativistic equations of motion when speeds are much smaller than that of light (e.g., for all macroscopic objects under normal conditions).

Further observations of the atomic and subatomic phenomena led physicists to observe that waves sometimes behave like particles and particles sometimes behave like waves. Newton's equations were replaced by Schrodinger's wave equation, and the relativistic version of Newton's equations was eventually replaced by relativistic quantum field theory. Armed with a relativistic quantum theory, physicists began to discover new particles and interactions, eventually producing the standard model of particle physics, which is valid down to the smallest distance scales we have been able to observe.

But is this creativity or discovery? The distinction here is subtle. True, these mathematical concepts cannot be directly observed. But I assume any intelligent species, living in similar conditions to our own, will "create" these same

[7] This is drastically oversimplified.

[8] This last part became so difficult that physics divided into theoretical and experimental physics.

mathematical concepts. They will even end up with the "same" laws of physics. It is even likely that their progress will resemble ours at first, from mechanics to electromagnetism. The precise order of discovery will differ, and the symbolic representation of mathematical concepts will differ from intelligent species to intelligent species, but there will probably be great individual minds who forge the significant breakthroughs required to build a complete theory of nature.

These examples are by no means complete, or even representative of all the types of creativity required in physics. I have completely ignored the creativity required to design and build experimental equipment. Modern physics experiments can be seen from space, relying on generation after generation of increasingly sophisticated devices, each generation studying phenomena that had to be manipulated and fully understood to create the succeeding generation of measurement devices. Nor have I sought examples of lesser creativity, the sort of creativity strewn throughout the exponentially growing physics literature. Mistakes and misconceptions have led to many great breakthroughs, unintended creativity.

It is not possible to disentangle the history of creativity in mathematics and physics. Where their histories intersect are many of the greatest developments in both fields. The invention of Cartesian coordinate systems and the calculus are excellent examples. Physics and math are like interwoven streams, flowing into and out of each other throughout their courses. At times, mathematical physicists are driven by necessity, while at other times, they are driven by the beauty of their equations. The equations hint at connections, and the drive for unification leads physicists to increasingly elegant theories containing fewer and fewer "arbitrary" constants, which seem to simply be hardwired into our particular universe.

It is now routine for theoretical physicists to create new universes. Change a fundamental constant, like the charge of the electron or the mass of a quark, sometimes even slightly, and the early evolution of the universe changes drastically. All of the nuclear fuel might be consumed long before stars are born, or chemistry might change so drastically that the macromolecules required by life cease to exist. As in all fields, the range of creativity seems to be limited only by our imaginations.

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Chapter 6
Fostering Creativity in Undergraduate Chemistry Courses with In-class Research Projects

Ted M. Clark

Abstract Chemical educators have viewed creativity in different ways, ranging from spontaneous "eureka–moments," to informed hunches, to a skill that may be practiced and improved upon. Intertwined with these descriptions is consideration of what chemists do, how they seek and solve puzzles, and how creativity plays a role. When it comes to educating students in chemistry, traditional laboratory instruction has presented limited opportunities for promoting creativity and decision making. This has begun to change, however. A promising pedagogical approach for fostering creativity in chemistry is the inclusion of in-class research experiences in introductory courses. The Research Experiences to Enhance Learning (REEL) program is an exemplar of a program that has introduced more than 10,000 students to in-class research in Ohio. REEL courses diverge from traditional instruction in many ways, and in this chapter, aspects of the program that foster creativity are discussed. Student perspectives on REEL laboratories are quite positive, with their opportunity to creatively propose and explore research their own questions an important consideration.

Keywords Chemistry education · Research experiences to enhance learning · REEL · Creativity · Decision making · Pedagogy

> A major challenge and barrier for many new research scientists is the need to work imaginatively and creatively: to have ideas for a new research project, or to find a new way of tackling an old but unsolved problem. During a typical science degree course, students acquire immense amounts of knowledge and learn to understand complex ideas and interrelations. But to a large extent they are spoon-fed from a curriculum and have neither the need nor the motivation to come up with truly new ideas.
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> —Ascheron and Kickuth, *Make Your Mark in Science*

T.M. Clark (✉)
Departments of Chemistry and Biochemistry, Research Experiences to Enhance Learning (REEL), The Ohio State University, Columbus, USA
e-mail: tedmclark@gmail.com

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> If two teams, pursuing rival research programmes, compete, the one with more creative talent is likely to succeed- unless God punishes them with an extreme lack of empirical success. The direction of science is determined primarily by human creative imagination and not by the universe of facts which surround us. Creative imagination is likely to find corroborating novel evidence even for the most 'absurd' programme, if the search has sufficient drive.
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> —Imre Lakatos, *Falsification and the Methodology of Scientific Research Programmes*

The role of creativity in leading to scientific discoveries is a fascinating topic. Historians and philosophers of science, psychologists, educators, cognitive scientists, sociologists, and others, have all found this area of study rich for analysis and discussion. Instead of surveying this entire field, attention is focused here on creativity as presented by chemical educators, the insights they have gained from these other domains, and the manner in which undergraduate chemistry courses include practices that hinder or promote student creativity. When examined in this way, creativity is found to be enigmatic, a concept not easily defined, and one that presents numerous contradictions for chemists, chemical educators, and chemistry students.

There is a long-standing consensus among chemists that creativity is an essential element of their discipline, with some holding that creativity may be regarded as "the chemist's most valuable asset" (Cope 1961). Some philosophers, such as Lakatos, go further, making the bold assertion that creative imagination in the sciences trumps all, including empirical data and "facts." Chemists may recognize the value of creativity, but it is unusual for them to reflect on practices that promote creativity. Indeed, many chemists (and other scientists) view creativity in an unscientific manner, referring to "inspiration," "hunches," or "eureka-moments" (Ascheron and Kickuth 2005), suggesting that creativity is not something that can be learned or studied and that "the creative act is a mysterious one" (Duke 1972).

Chemical educators agree that scientific inquiry involves creativity and that, to be scientifically literate with an understanding of the Nature of Science (NOS), one should understand the role of creativity, i.e., while scientific knowledge is empirical and testable, it is also partly the product of human inference, imagination, and creativity, and involves the invention of explanations (Abd-El-Khalick et al. 1998). However, in practice, this full description of science is not included in most chemistry courses. Therefore, students do *not* generally improve their NOS understanding in courses. Compounding the situation is the fact that representations of NOS in chemistry textbooks were poor and, over the last four decades, have gotten worse (Abd-El-Khalick et al. 2008). One of the more candid approaches is taken by a popular chemistry textbook when it admits to the student (and teacher) that "just because we can spell out the results of science so concisely and neatly in textbooks does not mean scientific progress is smooth, certain and predictable" (Brown et al. 2012). The chemical educators and book authors therefore present a mixed message; creativity is important, but it will not be integrated into the curriculum, will be absent from their textbook, and will probably remain hidden from the students.

An aim of this chapter was to help make sense of these contradictions surrounding creativity and its role in undergraduate chemistry instruction. This will involve consideration of what chemists "do," how these activities may involve creativity, and how chemistry laboratory courses promote or discourage original thought. This is followed by a description of an innovative program that has included thousands of students in in-class research experiences, how this program provides opportunities for student creativity, and how students have benefited from this opportunity.

6.1 What Chemists "Do"

To an undergraduate chemistry student, it is apparent what a chemist studies, i.e., "matter" in the form atoms, molecules, and compounds, which are involved in chemical and physical changes. Through laboratory experiments, a student may be introduced to simple laboratory resources such as balances or Bunsen burners, glassware (volumetric flasks and beakers), and techniques (filtration and distillation). In advanced undergraduate classes, modern instruments and sophisticated laboratory techniques are typically introduced and the subject matter becomes more specialized and discipline-specific, with courses in organic, physical, analytical, or inorganic chemistry.

Knowing what chemists study and the tools and techniques they employ does not really communicate what chemists "do" and how they generate new chemical knowledge. For undergraduate science students, the "scientific process" and how scientists "do what they do" is not well understood. When asked to provide a description, their response may include the view that scientists strive to discover the deepest mysteries of the natural world. This is accomplished by employing a foolproof method built upon logic, observation, and reason. Occasionally, true insights arise, not from logic, but from chance or imagination, as the scientist suddenly views the world in a new way, e.g., after being struck on the head by an apple. Is there any truth in this description? Is this how scientific knowledge is generated?

In some respects, chemistry is indeed coldly analytical, ruled by logic, observations, and the desire to produce testable and reproducible results. Although the failings of a simplistic hypothetico-deductive model of science have often been identified (Lakatos 1970; Collins and Pinch 1998), it may also be argued that some chemical research is conducted with very limited objectives and therefore it is possible to obtain such complete data that only a limited number of conclusions are possible. In these instances, it is possible to investigate phenomena by adhering to simple rules, leading one scientist to state he could solve *any problem* "by varying only one thing at a time, and to make note of all you do" (Platt and Baker 1931). Solving problems of a limited scope are certainly a part of what a chemist does, but they do not require a "flash of genius" or a leap of imagination and do not encompass the range of activities of a chemist. Working in the chemical industry, for example, it is not enough to execute and analyze an experiment, but one must also identify the most important experiment, design the experiment, select the runs, apply the results economically, and communicate the results to peers

(Drake et al. 1994). In this context, constructing experiments with single variables and making careful observations may be a problem-solving strategy, but not a chemist's sole activity.

One of the more influential descriptions of the scientific enterprise was proposed 50 years ago by Kuhn (1962, 1970a). Kuhn argued that, for most of the time, chemists (and other scientists) participate in "normal science." Scientists function in a particular research paradigm that defines legitimate problems and methods. A research paradigm is sufficiently open-ended to leave problems to solve and unprecedented enough to attract followers (Miller 1996). Normal science is a period in which scientists seek to enlarge the current paradigm by puzzle solving, and this enterprise accounts for the overwhelming majority of the work done in basic science.

The puzzle solving of normal science is not about discovery and, according to Kuhn, in no sense are such activities directed to disproving current theory. Instead, "the scientist must *premise* current theory as the rules of the game" as they seek to solve a puzzle, preferably one at which others have failed (Kuhn 1970a). Any "discovery" made within the confines of normal science is typically an improvement in what is already known. Improving the precision of an instrument, synthesizing a new compound or increasing the reliability of an analytical approach all are examples of puzzle solving and are part of normal science for a chemist.

Criticism of Kuhn's description of paradigm change and normal science has been both raised (see Popper 1970; Feyerabend 1970, and others) and responded to (Kuhn 1970b). The intention here is not to enter into this debate, but rather to point out that chemical educators are beginning to embrace Kuhn's views when considering the instructional style of activities they design to educate students (Domin 2009). In terms of creativity, the description of chemists primarily as puzzle solvers participating in normal science provides a useful middle ground between those scientific acts with limited creativity, such as replicating the works of others, and those at the other extreme that are strikingly original and lead to radical, monumental discoveries and revolutionary paradigm shifts.

6.2 Chemists and Creativity

What is creativity, and does it play a role in a chemist's puzzle solving? Creativity is readily associated with artistic activities, but what about scientific ones? It is perhaps telling among the Muses, nine goddesses of inspiration in Greek mythology, only one (Urania) was associated with a science (astronomy) and the rest with activities clearly linked to artistic creativity, such as dance, poetry, or music.

Creativity is not easily defined, and the manner in which new ideas arise is not obvious. Descartes proposed that ideas are the combination of other ideas, be they innate or observed. A hippogriff, chimera, or other fantastical creature or monster from our imagination is the combination of other features we have observed. In these terms, a creative idea is one that combines other ideas or observations in an original way. In scientific literature, one finds expansive, poetic definitions, such as “the faculty of mind of spirit that empowers us to bring into existence, ostensibly out of nothing, something of beauty, order or significance” (Medawar 1959). Others are more pragmatic, suggesting “creativity can currently be defined or described in an operational but not in a fundamental way. A creative person is one who originates unobvious, ingenious, and significant ideas” (Duke 1972).

The activities associated with puzzle solving may involve conceiving a research question, planning the project, designing experiments, analyzing results, thinking carefully about the best way of presenting scientific findings, convincing the audience of the correct interpretation, etc. (Ascheron and Kickuth 2005). To some degree, all of these activities are accomplished by referring to norms within the dominant research paradigm. A research community may have formed a consensus as to what a particular instrument does (how it functions, what it measures), acceptable laboratory procedures (how to separate a mixture, synthesize a compound), or suitable approaches for analyzing data (which statistical tests are applicable). For a scientist operating within this paradigm, such accepted strategies and procedures are applied to solve puzzles. The scientist does not need to reinvent these practices, but instead uses them with the understanding that others operating within the same paradigm will both recognize and expect such conventions. Much research is therefore routine, with certain methods being used and others that are not. In the field of chemistry, many of these norms are quite robust as highly specialized instrument, techniques, and methods of analysis are used to investigate the natural world. To say there is a “method” for solving scientific puzzles is to recognize that many research communities share common puzzle solving attributes when it comes to making observations, analyzing data, or communicating results, but these may become more specialized when situated in the research community of a narrower sub-discipline.

Considering, then, the different activities associated with scientific research, what does it mean to conceive of a research question, to what extent is this creative, and is it possible to learn to do this? Scientific creativity is not only the process of finding answers, but also in asking the right initial questions. As the opening quote by Ascheron and Kickuth suggests, the generation of research questions is a creative undertaking that many new researchers are ill-equipped to do.

An interesting perspective on this subject, offered by Miller, recognizes that creativity is critically important for practicing chemists, that it is largely ignored in their education, and that, in terms of generating research questions, it is a skill that can be learned (1996). Applying Kuhn’s model of normal science, Miller suggests that chemists typically solve puzzles that fit into a limited number of categories: They choose a molecule to synthesize or study, choose a reaction to study or improve, choose an interaction to study, choose a physical method to develop and understand, choose a theory to develop and understand, or choose a physical method to develop. A “bottom-up” approach then takes existing work in one of these areas and considers the “next” experiment that can be done to learn more. Miller has found that students are capable of generating new ideas in this manner, but many reject this approach for producing research questions until they learn that it is actually both acceptable and common to do so. These next-step experiments need not be very creative, but should have a high probability for success. Such bottom-up questions may be contrasted with “top-down” research questions, more creative proposals conceived to provide insight into unsolved problems with the potential to significantly change a field.

Once a chemist has a research question, is the subsequent puzzle solving process creative? Creativity may accompany the generation of questions, but isn’t there a “scientific method” that leads to their resolution? Even a cursory inspection of the historical record of scientific investigations reveals that “discovery is not the cold, unemotional exercise in logic that one might suppose” (Brown 1977). As the celebrated scientist Max Planck stated, “a scientist must have a vivid intuitive imagination for new ideas not generated by deduction but by artistically creative imagination.” For Ascheon and Kickuth, the key phase here is “not generated by deduction,” as lateral thinking is required, seeking new ways to look at a problem, viewing it from new angles, not merely proceeding by logical steps from what is already known or believed (Ascheron and Kickuth 2005).

An influential model describing the different stages accompanying creative problem solving was proposed by Graham Wallas early in the twentieth century (Wallas 1926) and has been cited by the chemical education community. These stages are (1) preparation, in which a person gains experience and insights in their field of study, (2) incubation, where the mind goes over the information acquired during preparation, (3) illumination, the “flash” of a new idea, and (4) verification, in which efforts are made to see if the idea actually solves the problem.

In some cases, the preparation stage is largely sufficient for reaching an answer, especially if the question is a modest extension of a previously answered puzzle. There are other questions, however, for which accumulation of data does not present an obvious solution and when a new idea is required. For some, the illumination stage is crucial for “although the collection of facts is an important first step, it is not the principal way that scientific breakthroughs occur” (Brown 1977). With illumination, disjointed facts are formed into a whole so that a new pattern emerges. At this point, too close a concern with details or facts, or even too much attention to what you are doing, can be severe hindrances. This moment involves a suspension of reason, an illogical or irrational element, and creative insight (Brown 1977).

Others, however, choose to represent the illumination stage in less dramatic fashion. In an extensive investigation of creativity as experienced and practiced by chemists, Platt and Baker describe incubation as the mental preparation for a “hunch,” and illumination the appearance or recognition of this hunch by our conscious minds (Platt and Baker 1931). The hunch is not overly mysterious and “shades imperceptibly into conclusions arrived at by more conscious reasoning.” It remains distinct from such reasoning, however, because although it may depend on a wider knowledge of facts, it requires a leap of imagination, going beyond “a mere necessary conclusion which any reasonable man must draw from the data at hand.” Put another way, it is a judgment for which the bases or premises are unknown or not clear to the individual having the hunch.

There are many examples of scientists gaining sudden insights through "eureka-moments" for problems of historic scientific significance. Many times such insights arise from the subconscious, or when the scientists stops actively thinking about the problem: "Kekulè was half asleep," "Loewi was awakened suddenly," "Werner was asleep," "Faraday took a holiday" when breakthrough ideas appeared for them. For de Laplace "by ceasing to think for some days on some very complicated question, it became quite easy to me when I consider it afresh" (Brown 1977). To add to this historical data, Platt and Baker went on to survey more than 200 chemists and found that 33 % reported frequently having hunches and 50 % occasionally having hunches when solving research questions. What is significant here is that both normal science, just like revolutionary science, often includes a creative leap, a moment of illumination, or at least an intuitive hunch.

Platt and Baker identify several conditions for successful incubation of ideas leading to a hunch, including an intense interest in, and accompanying focus on, the question; having information relevant to the question; having a systematic understanding of this information; having mental well-being and being free from interruptions; and stimulation from others. The resulting picture is that of a person actively thinking about a question and gathering information. This information is categorized, but the linking of ideas to form original ideas does not immediately occur. With enough information and perhaps with time away from the problem, the subconscious may supplement ones conscious reasoning. As one chemist stated, "you can go through this long, hard period of filling yourself up with as much information as you can. You just sort of feel it all rumbling around inside of you, not particularly at the conscious level. Then—it can happen at any time—you begin to feel a solution, a resolution, bubbling up to your consciousness" (Duke 1972). Or as another states, "the brain does a great deal of unconscious work without our knowing it, and that is how most of our great problems are solved. We must think very hard, but that is just 'priming'. It will mostly get you nowhere" (Duke 1972). As an aside, it is interesting to note that scientist's descriptions of these transformative moments, when new ideas seem to arise from the subconscious, parallel in many ways the role of the subconscious and an "incubation period" leading up to religious conversions as described by William James in his seminal work on religious experiences (James 1906).

The notion that puzzle solving requires gathering information (preparation), conceiving new relationships among ideas (incubation and illumination), and then evaluating the ideas (verification) can be supplemented by a model that characterizes intelligence as fluid or crystallized. As proposed by the psychologist Raymond Cattell in the early 1970s and then expanded on by others, fluid intelligence is the ability of younger brains to form and reform connections between neurons and describes mental flexibility, e.g., speed of understanding problems, of learning new content, developing new ideas, reacting quickly and appropriately in a new situation. In contrast, crystallized intelligence relies on memories and fixed neural pathways and is identified with what is commonly referred to as wisdom, e.g., problems are solved by drawing on experience and finding analogies. This perspective on intelligence and creativity, by recognizing stages for puzzle solving paired with different modes of intelligence, is fuller than a simplistic description of scientific creativity as a dichotomy, requiring an undisciplined, irrational, and unfettered creative spirit, paired with a coldly logical and keen analytical mind (Brown 1977).

Finally, having suggested that puzzle solving in normal science includes both imaginative hunches and logical reasoning, it may also be true that revolutionary ideas are not due solely to isolated, irrational "eureka-moments." Although there are "moments of profound insight in science, when, in what seems a blinding flash of conceptual change, the very way we think about the natural world is altered," it does not imply that such ideas support the popular image of scientific discovery, i.e., they are fully developed and provide instant insight the moment of their birth (Nersessian 2008). Instead, it is possible to view conceptual innovation, even the most dramatic, as part of a lengthy, organic process and that conceptual change, the use of analogies, and thought experiments are powerful forms of reasoning that go hand in hand with experimental investigations and mathematical analysis (Nersessian 2008). When described in this manner, both fluid and crystallized intelligences are part of the creative process, with past experiences and the ability to use and find analogies being important attributes.

Although it is beyond the scope of this chapter to consider whether creativity in other realms, such as painting, music, or poetry, is similar to the puzzle solving of scientists, it is informative to consider the process and products of such endeavors and to compare scientific knowledge with artistic achievement. For both scientists and artists, "the creative process often is convoluted, backtracking is common, and artists often realize what they are looking for only at the end" (Crease 2003). Differences do exist, however.

In art, a creative idea may be beautiful, moving or even shocking, whereas the aim of scientific ideas is to convince, explain, or provide the solution to a problem. In science, creativity is directly associated with gaining new insights into the workings of nature and solving puzzles (Ascheron and Kickuth 2005). In both the arts and science, practitioners struggle to innovate and seek individualized paths, but the assessment of those who fail in their quest for originality (and only produce "derivative" work) is noticeably absent from scientific discourse (Kuhn 1970b). Also, as a "mature science" (to use Kuhn's terminology), chemistry progresses in a more obvious way than do the proto-sciences, such as the arts and philosophy, or even chemistry did before the mid-eighteenth century (Kuhn 1970b). The reason for such progress is not entirely settled, but a key element is certainly the fact that mature sciences make concrete, testable predictions about natural phenomena (Popper 1970; Kuhn 1970b). Are these scientific insights and predictions inevitable? For a scientific realist, the structure of the world is prefigured and scientists seek to uncover the existing structure. Imagination and creativity (and logic and reasoning) may affect when scientific knowledge is generated, but not the structure of the final understanding (Crease 2003). In contrast, a symphony by Beethoven, a novel by Faulkner, or a building by Frank Lloyd Wright are not inevitable and would not necessarily exist absent the creativity of a particular individual. Although there is some truth to this comparison, such a stark contrast fails to appreciate the creativity inherent in designing and carrying out a well-designed experiment. The process of experimentation is far from certain and experimental work involves a different kind of ingenuity, also dependent on imagination and creativity, which is not inevitable (Crease 2003).

What, then, is an apt characterization of scientists, scientific discovery, and creativity? Scientists solve puzzles that require various degrees of ingenuity and creativity, with some puzzles derived from previous investigations and others being more novel. Elements of a "method" are applicable, such as observations, seeking reproducibility, and applying reasoning skills, but these may not be sufficient to solve the puzzle. Looking at it from new, original directions and forming new connections between existing ideas may be required. A scientist more familiar with existing ideas may, therefore, have richer mental models that can be combined in novel ways. However, having such knowledge is not the only factor. It is possible that ideas and new connections may arise unexpectedly, be they startling leaps of imagination or more subtle hunches, especially if the scientist has been focused and actively thinking about the puzzle. Interestingly, such insights may occur once the mind has added and mentally categorized information and then takes a break from actively thinking about it. They may also be formed by use of analogy, thought experiments, and other forms of reasoning. These resulting ideas are not inherently "right" and will therefore require testing and evaluation; an experienced scientist may by better prepared to judge the merit of the possible solution. Finally, scientific discoveries often involve both experimental and theoretical elements, both of which spring from the human intellect, and both of which frequently require ingenuity and creativity.

6.3 Undergraduate Chemistry Laboratories and Creativity

Having described the persistence need for creativity by practicing chemists, one might expect that undergraduate chemistry courses would seek to encourage creativity, aiming to train future chemists, or in an effort to communicate an authentic description of the field. The most obvious location for such efforts would seem to be chemistry laboratory courses, which are ubiquitous in the undergraduate curriculum, and seem to offer the potential for both the training of students and communicating the nature of chemical investigations.

There is general agreement that science laboratory instruction may be used to address multiple goals; whether it actually lives up to this potential is debatable. Stated aims of laboratory instruction often include mastery of the subject matter, developing manipulative skills, gaining insights into NOS, cultivating interest in science and science learning, learning to work independently and/or in a team, and developing scientific reasoning skills. This final aim is multi-dimensional and includes objectives such as being able to identify questions and concepts that guide scientific investigations, designing and conducting scientific investigations, developing and revising scientific explanations and models, and making and defending scientific arguments. In short, the aim is to develop abilities to investigate the material world and make meaning out of these investigations (National Research Council 2006). Chemical educators have recognized that creativity is intimately connected to several of these aims, e.g., NOS understanding and problem solving, and may be part of others, such as cultivating interest in science. It is not clear, however, that such connections are being made in undergraduate chemistry laboratories or classrooms. As noted previously "(students) are spoon-fed from a curriculum and have neither the need nor the motivation to come up with truly new ideas" (Ascheron and Kickuth 2005).

The instructional style of a laboratory course strongly influences the level of creativity. Four laboratory instructional styles have been prevalent throughout the history of chemistry education: expository, inquiry, discovery, and problem-based. As shown in Table 6.1 (from Domin 1999), these may be differentiated in terms of the outcome, the approach, and the procedure for the laboratory. Far and away, the most common form of laboratory instruction is expository in which students follow a given procedure and apply deductive reasoning to reach a predetermined outcome. The strength of this approach lies in its logistical framework as activities can be performed by a large number of students simultaneously with minimal involvement from the instructor. Given the daunting logistical constraints of providing General Chemistry laboratory experiences for the large number (hundreds or thousands) of students common to many higher education institutions, it is unsurprising that expository laboratories are commonplace.

Criticism of expository laboratories is widespread among science education researchers and such criticism has been voiced for decades (Schwab 1962). The often-repeated "cookbook" description of this laboratory format emphasizes the following of specific procedures to collect data and so little attention is given to planning or interpreting the results. It has been argued that no meaningful learning takes place in these laboratory spaces (Tobin and Gallagher 1987) because students spend more time determining if they obtained the correct results rather than thinking about the scientific principles being applied in the laboratory, and also because these traditional laboratory activities are designed to facilitate the development of only lower-order cognitive skills such as rote learning and algorithmic problem solving. Indeed, chemical educators offering pedagogical strategies for promoting student creativity often begin by citing the deficiencies of scripted, expository instruction (Acheron and Kikuth 2005; Drake et al. 1994; Buono et al. 1973;

Table 6.1 Description of laboratory instructional styles

Style	Outcome	Approach	Procedure
Expository	Predetermined	Deductive	Given
Inquiry	Undetermined	Inductive	Student generated
Discovery	Predetermined	Inductive	Given
Problem-based	Predetermined	Deductive	Student generated

Domin (1999)

Ditzler and Ricci 1994; Miller 1993; Venkatachelam and Rudolph 1974; Lipkowitz and Daniel Robertson 2000; Gallet 1988; Zielinski 2009; Scott 2010).

Domin has also shown how these different laboratory instructional styles relate to Kuhn's description of the scientific enterprise (Domin 2009). For example, the pervasive expository instructional style is similar to what scientists "do" when they seek to replicate another scientist's work and validate their findings. However, as Domin notes, mindlessly following a recipe from a laboratory manual is a poor approximation of this task.

Kuhn's description of normal science as puzzle solving is a natural match for problem-based laboratory assignments. Domin holds that such assignments can help students understand that scientists often employ deductive reasoning to achieve a "predetermined" outcome. A student's task is predetermined in that the instructor already knows the correct answer; a scientist's task is predetermined in that normal science is not about new discovery, but rather an improvement in what is already known. For Kuhn, a true scientific discovery involves a radical change in our worldview. In terms of instruction, this is akin to conceptual change that may accompany guided or open-inquiry instruction. A scientific discovery, such as inquiry learning, may be an inductive process leading to the construction of a new generalizable understanding. For Domin, guided or open-inquiry tasks best simulate scientific discovery.

Problem solving of any kind is largely absent from expository laboratory tasks. The notion that "a problem exists when a person perceives a gap between where he or she is and where he or she wants to be but doesn't know how to cross the gap" (Hayes 1981) has been adopted in studies of chemistry students' problem solving (Gabel and Bunce 1994) and serves to distinguish problems from exercises (those tasks for which a strategy is known and applied). Students following a laboratory recipe are, at best, completing an exercise. This is not to say that a scientist's replication of another's work is a simple, routine task. As noted by Crease, and as many scientists will affirm, the crafting of an experiment (even when replicating another's work) involves considerable decision making and a clear "gap" that must be bridged. This kind of problem solving is not, however, incorporated into traditional expository instruction.

All problem solving does not require the same degree of creativity. Indeed, while chemical educators have examined many aspects of student problem solving, e.g., how students combine conceptual scientific knowledge and procedural knowledge, their ability to decode or translate the words in a question, to apply mathematical skills, etc., far less attention has been directed to the role of creativity (Gabel and Bunce 1994). The questions or tasks in most science courses have clear objectives, obvious solutions (to an expert), and come with complete information. These are termed well-structured or semi-structured questions. In contrast, an ill-structured problem tends to be complex, non-routine, and difficult to define. Potential alternative solutions exist, and creative solutions are required (Ellspermann et al. 2007). Ill-structured problems like these have been give wonderful titles, such as "a mess" (Ackoff 1979), "wicked situations" (Rittel and Webber 1973), and "swampy situations" (Schon 1987).

Many authentic problems confronting chemists are ill-structured, requiring creativity. If the traditional chemistry curriculum fails to incorporate creativity, how was this skill developed? Returning to Wallas's model of preparation, incubation, illumination, and verification, some hold that the goal of undergraduate science instruction must be providing students with experience and insights into their field of study (the preparation stage). With this foundation, the chemist may be capable of reaching the other stages (incubation, illumination). While there may be some merit in this approach, it is a curious strategy for fostering creativity, or for encouraging interest in science, or for providing insights into how science is conducted. For many educators, such a trade-off is untenable and should suggest a different path. As one states, when reflecting on their own education and now their role as a teacher moving away from expository instruction, "why go through such a drastic change that would question everyone's beliefs and convictions about chemistry teaching?…I think that developing imagination, scientific creativity, and intellectual autonomy is far more important than the accumulation of cold knowledge" (Gallet 1988). Perhaps most strikingly, an approach of facts first, creativity later (if at all) completely fails to communicate the role of creativity in science for the vast majority of students that will not choose to enter into a scientific profession.

An alternate approach is to recognize that many of a scientist's "routine" tasks are novel for an undergraduate student. For a student learning scientific conventions and norms, many seemingly mundane tasks are opportunities to express creativity. Choosing a title for a laboratory report, designing a data table, or preparing a figure, may involve student-decision making. All too often, however, such choices are removed in favor of uniformity for logistical or pedagogical reasons, e.g., students are given fill-in-the-blank data report forms for ease for grading. It may be argued that such rigidity not only reduces routine tasks to "preparation", but also limits the effectiveness of the preparation stage by removing critical thinking and decision making.

An even more ambitious strategy is to involve students in authentic in-class research projects. Chemistry is, by its nature, an experimental science. However, the cognitive skills neglected in most introductory level chemistry laboratories are exactly those needed for success in chemical research; this includes both analytical skills and creative problem solving. Real research inherently involves a more independent and open-ended type of thinking which permits the frustrations of failed experiments, the challenge of learning from failures, and occasionally the exhilaration of successful experiments.

Participation in undergraduate research has evolved from a cottage industry of individually arranged student–professor research projects to institutionalized efforts that now reach thousands of students (Blanton 2008). The considerable enthusiasm among stakeholders such as administrators, faculty, students and parents for broadening participation is certainly due to the range of potential benefits, including gains in student engagement, retention, and content learning. The culmination of this trend toward broadening participation in undergraduate research is reached when in-class research experiences are embedded in introductory courses that enroll a large number of students.

Unlike the momentum currently accompanying initiatives aiming to expand research experiences, the deficiencies of traditional expository-style laboratory instruction have long been decried by educators, yet logistical and institutional inertia have limited meaningful transformation. Only a minority of students at research-intensive universities have opportunities for active learning or real-world problem solving in introductory courses, leading to the conclusion that reform aiming to introduce research-grounded teaching methods (which usually favor active learning) in STEM departments have largely stalled (Laursen et al. 2010).

Although the aims and outcomes for those espousing programs that broaden participation in research and those advocating change in laboratory pedagogy frequently overlap (e.g., student epistemological growth and attitudinal change), the former currently have far greater momentum and, indeed, the considerable attention funding agencies have given to undergraduate research programs may be due to the fact that gains accompanying such participation are viewed by policy-makers as being more "solid" and assured (Laursen et al. 2010). It is fortunate, therefore, that these paths converge pedagogically with the inclusion of authentic in-class research experiences in student laboratory courses. Initiatives aimed at broadening participation in undergraduate research may also be having the (unintended) consequence of promoting student creativity in the sciences. One such initiative, implemented on a massive scale and including thousands of students, is the Research Experiences to Enhance Learning (REEL) program. Examination of REEL is valuable, with attention given here to how creative opportunities were offered to students on a very large scale, and how students benefited from these opportunities.

6.4 A Model for in-Class Research Experiences

The Ohio Consortium for Undergraduate Research: Research Experiences to Enhance Learning (OCUR-REEL) Project, an Undergraduate Research Center (URC) that received funding from the National Science Foundation between 2006 and 2011, included the chemistry departments at institutions spanning the State of Ohio, including community colleges, liberal arts colleges, and research universities.[1] REEL's central goal was the transformation of undergraduate science education by providing authentic in-class research opportunities to a large number of students at institutions of higher education, thereby broadening undergraduate participation in science, technology, engineering, and mathematics (STEM) research. Research was to be in the chemical sciences with projects providing exposure to areas of contemporary scientific interest, addressed with modern research tools

[1] Higher education partner institutions included the University of Akron, Bowling Green State University, Capital University, Central State University, University of Cincinnati, Cleveland State University, Columbus State Community College, University of Dayton, Kent State University, Miami (OH) University, Ohio University, the Ohio State University, University of Toledo, Wright State University, and Youngstown State University.

and methods, thereby allowing students to create new potentially publishable knowledge. Learning in these settings was to be discovery-based, providing students with the opportunity to creatively participate in the communication of scientific knowledge. With REEL, student participants were enrolled in REEL courses in an inclusive manner at the earliest possible stage of the collegiate experience, including those who would not otherwise be involved in conducting original research in the chemical sciences (Clark 2009; Kahle and Li 2011). This strategy led to a very large number of participants, reaching ~2,500 each year and more than 12,000 in a 6-year period.

With REEL, the pedagogical strategy for achieving the transition from expository to active learning laboratory instruction and also broadening participation in undergraduate research centered on the development, testing, implementation, and dissemination of research modules in first and second year chemistry courses. Common characteristics of these projects included: (1) replacing 3–5 weeks of traditional laboratory instruction, (2) emphasizing student ownership of a research project, (3) students contributing to an overarching research theme that was informed by an authentic research program, (4) students working with classmates in small groups and receiving "expert" instruction from instructors, teaching assistants, or Peer-Mentors, (5) hands-on experience with modern instrumentation, and (6) summarizing findings in research papers, oral presentations, or poster sessions.

An in-class research experience must meet multiple objectives. They must be practical (i.e., are the costs, waste, manpower and instrumentation demands reasonable and sustainable), research-orientated (do the experiments lead to the generation of new results and knowledge), educational (does the content reinforce the existing material and foster critical thinking skills), and motivational (do students get excited about the research and develop a sense of ownership of the project)? In terms of creativity, these tasks must balance student-decision making with the need to "get good data." In other words, if the student-generated results are to be meaningful and contribute to the broader field of knowledge, they must be consistent with the research norms and practices within the field. However, having students follow a "recipe" to produce a particular data point in a research study presents no more problem solving than does an expository experiment. What is needed is a new paradigm for scientific research.

Typically, at a research university, chemical research is conducted by graduate students and/or post-doctoral researchers (and occasionally undergraduates) as part of a research group under the guidance of a faculty member. In this model, a relatively small number (perhaps 1–10) of highly trained investigators (capable of using advanced instrumentation, performing challenging syntheses) devote a large amount of time to address a problem. Suppose there are many different ways to explore a given problem. In this standard model, an initial point in the possible problem parameter space is selected, perhaps by referring to the scientific literature, or maybe based on a "hunch" by an investigator, or perhaps the "wisdom" (crystalized intelligence) of the faculty member. This problem-solving parameter space may involve seeking a better way to synthesize a compound (is the temperature important, what are the best starting materials?), the optimization of an

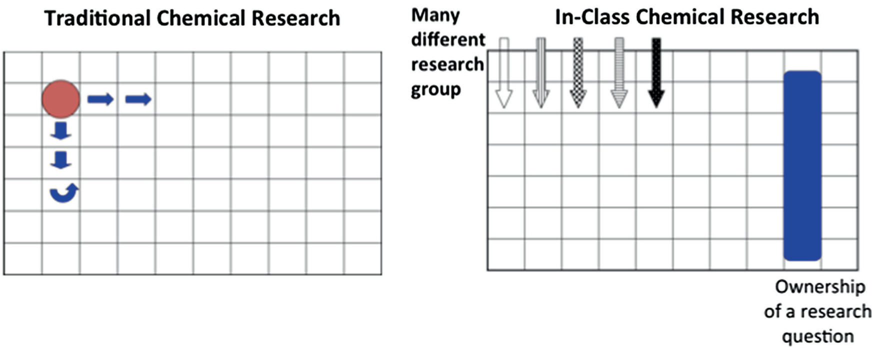

Fig. 6.1 Approaches for exploring a problem's parameter space. Traditional chemical research, in which initial conditions are selected and variables systematically changed, versus in-class chemical research with student groups proposing research questions that examine a subset of the variables

instrument (what kind of detector is best?), or how to collect samples for environmental testing. Returning to Kuhn's description, this is puzzle solving within a particular paradigm. Then, the researchers begin their investigation, manipulating variables, running tests, and making observations and inferences. Frequently, the researcher will conclude a change in strategy is needed and the problem solving moves in a different direction with different variables being manipulated (Fig. 6.1).

When in-class research projects are implemented in introductory science courses on a large scale the traditional model is dramatically changed. Instead of having a small number of investigators, hundreds of students may be involved. These "researchers" will be modestly trained and will commit only a small amount of time. Such a shift requires a rethinking of what resources are suitable and numerous questions arise, e.g., what instrumentation can be used, are there safety concerns, what can be accomplished in the fixed amount of time allocated to a laboratory course? Some research questions, however, truly benefit from a large number of investigators, even if they have a limited amount of time and skills. The field of combinatorial chemistry, in which a large number of different but structurally similar molecules are synthesized to meet a particular need, is closely aligned with this research strategy.

Having settled on a macroscopic research theme, the next challenge is to provide a framework that gives students the freedom to explore the parameter space and still produce "good" results that scientists will value. This includes providing students with sufficient background information so they can develop a "next-step" research question paired with adequate resources (e.g., training, standard operating procedures, protocols, and instrumentation) so student-generated results are acceptable. Absent adequate background information, the task of constructing a research question is understandably daunting. Sufficient instructional scaffolding is necessary, otherwise students will disengage from the task. Some educators have criticized students in these circumstances, offering that some students are "unwilling or incapable of coping with the novelty of being creative" (Lipkowitz and Daniel Robertson 2000). Such criticism fails to appreciate the difficulty of producing original ideas. Also, scaffolding is required to ensure student-generated results have meaning for others in the scientific community. This striving for authenticity and research-quality data sets in-class research apart from other inquiry-based laboratory experiences. Students are not simply solving an in-class puzzle, but potentially speaking to the larger research community in a meaningful way.

Environmental chemistry investigations are research projects that offer a large parameter space including both a unifying macroscopic research question and the opportunity for student-generated research questions within the overarching framework. For example, over a 3-year period at a single university within the REEL program, about one-thousand students collected and analyzed soil samples from a metropolitan area. The macroscopic research questions in this study were to identify regions of the city contaminated by heavy metals (such as lead or arsenic) and to investigate possible anthropogenic contributions to identify correlations between features such as expressways, railroads, or industry with heavy metal contamination. Working in groups students generated their own research questions that simultaneously contribute to the overarching theme, such as comparing the soil from modern and historic churches, comparing near-stream soil with that found near man-made lakes, analyzing the soil near local airports, testing construction sites, graveyards, or schools. The collection of samples and their analysis employed standard methods from the Environmental Protection Agency and produced high-quality results. This approach required creativity on many levels, beginning with the instructor designing the project, to the student groups that generated their research questions, and finally to the researchers seeking value in the student-generated results. Of course, when these activities are situated in instructional laboratories, logistical and pedagogical constraints abound. Is it possible to create large-scale research projects that are perceived by students as "real," or do students view such tasks as just another (unwanted) assignment? As a REEL student remarked, "I initially thought I would strongly dislike this REEL program. I felt like it would just be another science fair that, this time, I was unaware I had signed up for."

6.5 Are REEL Laboratories Different? The Student Perspective

Undergraduates involvement in summer and in-class research experiences has been extensively studied (see Lopatto 2009, for a review) with self-reported gains in areas that may involve creativity as it pertains to the process of scientific discovery. Several of the learning gains accompanying involvement research may be attained by well-designed learning experiences, such as skill in science writing or reading and understanding primary literature. Others, however, are more difficult to communicate without direct involvement in an authentic research experience. For example, tolerating obstacles faced in the research process is an abstract concept that does not acquire meaning until the researcher has such an experience. A similar generalization may be made for objectives such as clarifying career path, understanding the research process, gaining confidence, and developing a readiness for more demanding research (Laursen et al. 2010). Appreciating the role of creativity and imagination in scientific research is another concept that takes on added significance if experienced first hand. Is it possible to have students view research as a creative process when they participate in an in-class research experience? Since there are many logistical and pedagogical constraints when it comes to implementing in-class research projects on a large scale, do students view such courses as being different from traditional ones?

Students within REEL have consistently noted that these courses include course elements that differ from their traditional (expository) laboratories (Kahle and Li 2011). Upon entering a REEL course student self-report being proficient with completing scripted laboratory experiments, but express less confidence in assignments that include decision making. Following REEL laboratories, self-reported gains are greatest when it comes to working on projects "where no one knows the outcome," "where students have input into process or topic," and ones "entirely of student design" (NSF Report 2011). In comparison with non-REEL courses, students in REEL ones are more likely to "design activities to test their own ideas," "argue or debate with one another about the interpretation of data," "consider alternate explanations," or "talk with one another to promote learning." In contrast, students in non-REEL course are more like to "memorize scientific facts" or "learn science by studying the course textbook" (Kahle and Li 2011).

REEL student perspectives on creativity have been obtained with various end-of-course surveys and interviews.[2] A recurring theme in these interviews is that students identify REEL as open-ended, requiring creativity, and that it therefore is in stark contrast to expository laboratory instruction. Student comments, such as "I liked that we were given so much room to do what we wanted but yet we were still guided through it enough to get our desired results. It allowed you to think for yourself," and "I liked the idea that we were able to choose what we wanted to research. It was good to be able to test something you wanted to research instead of reading from a book and doing what it tells you," make clear that students may view the opportunity to take ownership of a project as a positive.

These interviews also made clear that students enjoyed REEL because it was **not** an expository laboratory ("I enjoyed how it was not just copy this procedure out of the book, do it word for word, go home, write a lab report, and do it again"), but instead a challenge requiring critical and creative thinking. This challenge was met, in many cases, by working with classmates. In some cases, the group work informed the students' data analysis; "by working in groups I had the opportunity to actually

[2] Student quotes are from open-ended surveys following their participation in a 3-week in-class REEL research project in General Chemistry. The number of students involved in a particular research project ranged from 150 to 450. Most students had already completed ~25 weeks of General Chemistry laboratory instruction (presented in an expository format) before beginning the research project.

discuss results and learn about how others view data differently." Group work was also valuable when generating research questions; "the aspects of the program that I enjoyed were working together with a group and forming a hypothesis. It was very interesting to work with a group who come from many different experiences to see what everyone can bring to the table. Working with groups is very important." As another student remarked, "I loved having a group because we could split the work and bounce ideas off each other. We are all intelligent students because we have made it to the end of General Chemistry so why not share the knowledge?"

Student insights into group work, and how it pertains to creating ideas, are important. It has been suggest that "probably the most important single source of new ideas (for scientists) are the personal exchanges between members of a research group…by exchanging ideas and combining different approaches to solving the same problem, new insights can be gained that neither party alone would have attained" (Ascheron and Kickuth 2005). It is remarkable to hear students offer similar comments based on their own in-class research experiences. The "bouncing of ideas of each other" is also clearly connected to brainstorming strategies frequently used to encourage creativity and problem solving.

Beyond being simply "fun" or "interesting" students also identify REEL's non-expository format as an approach for improving learning and critical thinking. As noted above, expository laboratory instruction fails to move learners beyond lower-order cognitive skills. REEL students articulate this point when contrasting traditional laboratories with the increased complexity of REEL laboratories:

> I liked that the REEL Project made me think. It wasn't like a traditional lab where everything was given to me and all I had to do was follow the steps. It required me to know exactly what I was doing and understand the concepts.

This finding aligns with the suggestion that personal and creative experiences may support not only students' enjoyment of chemistry, but also add to their ability to learn the material (Furlan et al. 2007). An emphasis on authentic, potentially publishable research is a defining characteristic of REEL that distinguishes it from other inquiry-based laboratory instruction. For some students, this opportunity to be "co-researchers" contributing to a larger research program is important and provides purpose that both motivates and leads to greater understanding:

> My favorite part of REEL is that your work has purpose. When doing other labs (in earlier courses) I often found myself wondering why I was even doing these labs in the first place. I didn't see labs as anything more than busy work and never understood why we did each particular lab. In REEL lab however, I was able to form my own experiment, which made doing the lab a lot more meaningful. The material was more applicable to real life which made it a lot easier to learn and follow.

In-class research projects require students to generate their own research questions, to engage in puzzle solving. This stands in contrast to the traditional curriculum of laboratory tasks and exams that "rewards students who can reproduce correct answers," instead of those who can "ask the right, or perhaps any, questions" (Brown 1977). A minority of students view this challenge unfavorably and it has discouraged them from seeking other research opportunities; "No, I do not want to do research. It is a very intense process and its very open-ended without a lot of guidelines." However, this may not be a negative result as such information is more valuable to a student early in their academic career rather than later (Lopatto 2009).

For most students, involvement in a REEL course is much more likely to increase their interest in pursuing research activities rather than diminish it. Unlike other programs aiming to broaden participation in research, the fact that REEL does not select or recruit students, opting instead to incorporate research in introductory courses serving large numbers of students, leads to the participation by students that did not have an inclination to pursue scientific research. For some of these students, REEL provides familiarity with research. As a student stated, "Personally, research scared me because I knew nothing about it. Now I know it is not that scary and can be brought down to the level that I understand." The transformation of some students, from fearing to embracing research, can be remarkable:

> At the beginning of the quarter I was dreading this research project (since) I had never really experienced scientific research. (However) I really liked the REEL project and feel like I got a lot out of the research experience. I think it will definitely help me in the future when I do more research. There were no aspects that I didn't like and this was the first chemistry course I've really genuinely enjoyed.

Transformations like these result from a confluence of factors including dissatisfaction with rigid expository instruction, a new-found confidence in one's ability to participate in scientific research, and a greater understanding as to what chemical puzzle solving entails. Most relevant for our current discussion of creativity, initial perceptions that science is practiced in a boring, confined manner (a viewpoint reinforced by traditional laboratory experiences) may be reshaped by involvement in projects like REEL:

> (REEL) altered my views. Everything we had seen before this had been clear-cut experiments with specific steps, and we were supposed to get specific results too. In these labs we could alter our procedure and deviate from the outline of what we were supposed to do. It was also refreshing to see other people with different results, and not just the same as my own. As a result it was easy to understand how many outcomes arise when you change the slightest thing in an experiment. This makes you understand and appreciate new findings in science.

In summary, students view REEL courses as a significant departure from traditional laboratory instruction. Students welcome, and are capable of, increased decision making and pursuing their own ideas when situated in the context of a larger research framework with sufficient scaffolding to support their investigations. It is significant that such a framework can accommodate hundreds of students at one time and may also serve students initially hesitant (or fearful) of undertaking a research project. For many, the challenge of moving into "swampy situations" to deal with ill-structured problems is a welcome relief from expository experiments that present a distorted view of normal science and stunt their intellectual curiosity.

Students in programs as REEL are puzzle solvers, seeking answers to bottom-up research questions. The practices that accompany this puzzle solving, things such as group discussions, seeking diverse views, brainstorming ideas, and talking with each other are the same practices scientists employ when they seek creative solutions. These may not be eureka-moments arising from the subconscious that produce ground-breaking discoveries or dramatic conceptual change, but they are examples of students applying their fluid intelligence and generating novel ideas.

The fact that student-generated ideas may also be part of a larger research program that produces, at times serendipitously, meaningful findings for a larger research community is also noteworthy. To make this possible, students must have research-quality instruments and sound procedures so that experienced chemists, when observing anomalous results, deem them worthy of further study and verification. This is a dramatic departure from scripted laboratories with predetermined answers that need to be confirmed (Chinn and Malhotra 2004). Unexpected anomalous results that requiring creative analysis are central to science. Indeed, research chemists view such occurrences as exciting moments, whereas students that experience anomalous results in a verification laboratory frequently choose to ignore the anomaly, change the data ("fudging" the results), or cheat (Samarapungavan et al. 2006). What programs such as REEL offer instead is an opportunity to come up with new ideas, not rationalizations why the standard results were not obtained. Returning to the opening quote by Ascheron and Kickuth, initiatives such as the REEL program make clear that today's science curriculum should combine both an understanding of complex ideas *and* the creative generation of new ideas. The next challenge is for administrators, faculty, and staff to act creatively and bring such a curriculum to fruition.

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Chapter 7
Creative Engineering Design: The Meaning of Creativity and Innovation in Engineering

Christine Charyton

> *The word "engineer" comes from the Latin "Ingeniatorum" meaning "ingenious" with "gen" Referring to Creation, the act of Creation or "Genesis" The essence of the words "creativity" "create" and "engineer" Stem from the act of creation.*
>
> *Creativity is no longer an optional accessory. Instead, creativity is a necessity for innovation and prosperity, especially now during our current global and economic times. Creativity and innovation are vital in the United States of America, the Americas, Europe, Asia and the entire world, especially now in our current era.*

Abstract The importance of creativity as a vehicle for innovation in engineering design is discussed in this chapter. A creative act needs acceptance of an idea, product, or process by the field, such as engineering and the domain such as science or Science, Technology, Engineering and Mathematics (STEM). Today's engineers must be creative and innovative. The problems engineers facing today demand original thinking. To remain competitive globally, engineering firms rely on creative individuals and creative teams to develop new products for innovation. The Creative Engineering Design Assessment (CEDA) offers a new method for assessing creative engineering design. **Unlike previous measures, the revised CEDA also measures Originality and Usefulness, which, to date, is a unique component when compared to other general creativity and engineering creativity measures.** Creative design and its measurement may act as a catalyst to increase enrollment in STEM. Through prioritizing creativity and innovation, as we did with prioritizing scientific creativity in the 1950s, we can enhance global prosperity, not only for the United States of America (USA) but also for other countries around the world.

C. Charyton (✉)
Department of Neurology, Ohio State University Wexner Medical Center, Columbus, OH 43210, USA
e-mail: charyton.1@osu.edu; Christine.charyton@osumc.edu

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7.1 Introduction

Creativity research in engineering began to blossom in the 1950s (Ferguson 1992). The recommendations of Vannevar Bush, an electrical engineer from MIT, led to establishment of the National Science Foundation in 1950. At the same time in psychology, American Psychological Association President, J.P. Guilford stated a need for creativity research (Guilford 1950). “The research design, although not essentially new, should be of interest” (Guilford 1950, p. 444). A creative pattern is in creative behavior, which includes activities such as inventing, designing, contriving, composing, and planning. People exhibit these types of behavior are recognized as creative. Guilford (1950) noted a key trait of creative people in that they have novel or new ideas.

In the early 1960s, the National Science Foundation (NSF) sponsored conferences on “scientific creativity.” Yet, “as interest in engineering design faded in most engineering schools, creativity was put on a back burner” (Ferguson 1992, p. 57). More recently, creativity has received greater attention as a necessity for engineering design (Charyton and Merrill 2009). Currently, creativity is increasingly important as a vital resource.

Creativity is the most important of all human activities. Many homes and offices are filled with furniture, appliances, and other conveniences that are products of invention (Simonton 2000). Czikszentmihalyi (1999) suggested that the person, domain, and field are relevant to understanding creativity and innovation. This theory postulates that there needs to be acceptance of an idea, product, or process by the field such as engineering and the domain such as science or Science, Technology, Engineering and Mathematics (STEM).

Creativity and innovation are key in most levels of engineering education, yet these topics are rarely expressed, investigated, or studied explicitly in coursework (Forbes 2008). Without training in the fundamentals of creativity, only 3 % of the population associate creativity with engineering (Stouffer et al. 2004). However, there is consistent interest in engineering education to address creativity and innovation within the curriculum. For example, Ishii and Miwa (2004) found idea generation, idea embodiment, and collaboration of creative activities as important activities for learning. Projects with a keen personal investment may increase the commercialization of invention (Ruiz 2004).

7.2 Why Creativity is Still Needed in Engineering Design

The problems engineers facing today demand original thinking. To remain competitive globally, engineering firms rely on creative individuals and creative teams to develop new products for innovation. Design News (2007) reported that 65 percent of engineers in the workforce (from mechanical, application, and manufacturing engineering companies) agreed that today's engineers need to be more creative and innovative to be globally competitive (Christiaans and Venselaar 2005).

Specific to engineering, engineers may increase creative production through understanding their domain-specific constraints. Stokes (2005) described how different types of constraints (tasks, goals, subjects, functions, materials, and styles) may be unique to specific domains. Research by Finke, Ward, and Smith (1996) found that the relative number of creative inventions increased significantly as the task became more highly constrained. Constraints on design may need further assessment as technology evolves (Mahboub et al. 2004; Redelinghuys 2001; Waks and Merdler 2003).

Engineers can learn to use tools such as technology for design (Jones 1995), yet human beings are vital (McDougnel and Braungart 2002) for innovation in design. Products are sometimes invented by users to improve our everyday lives in relation to social functions (Von Hippel 2005). For example, communication tools that utilize technology often benefit consumers. Engineers can foresee potential consumer needs for products. These products can increase productivity and contribute to innovation and the future of the engineering field (Jones 1995).

7.3 The Importance of Creativity and Innovation for Engineers Beginning in Education

Today's engineers must be creative and innovative; there is a pressing need that creativity and innovation in engineering begin in educational settings (Fleisig et al. 2009). The encouragement of creativity is vital in schools and curricula (Romeike 2006). Education has the power to cultivate or stifle creativity (Burleson 2005). Creativity is enhanced by confidence, self-development, and a positive mind-set (Kang et al. 2011).

Creativity may be expressed as visualizing and manipulating images, greater openness to experience, and evaluating ideas (Hawlader and Poo 1989). Ito et al. (2003) suggest that imagination is attained by touching the concrete. These authors also suggest that creative education enables students to make innovative products while promoting integrated cooperation. Sulzbach (2007) notes a recent graduate emphasized teamwork, leadership, creative thinking, and problem solving "-no grades attached. That is the engineering student I want to hire."

Engineering education is a paramount in providing the nation with innovative, creative, and critical thinking human capital that contributes to sustainability of the economy (Yasin et al. 2009). Creativity should be a vital part of engineering education as well as an important student outcome (Chiu and Salustri 2010) that contributes toward the workforce.

7.4 Creativity and Meta-Cognitive Abilities in Engineering Education

According to Nickerson (1999), creative problem finding may offer another avenue to increase creative production in engineering and needs further research. Furthermore, problem finding has not been a major focus of education. However, problem finding is common for an engineering designer needing to solve unforeseen problems (Ferguson 1992).

Psychology is valuable for addressing creativity in education by promoting learning through meta-cognition and self-reflective activities (Ishii and Miwa 2005). Empirical studies in educational and cognitive psychology literature address methods for learning. These methods have been implemented successively in engineering classes. Real-world applications, cooperative learning, active learning, and deductive and inductive learning are important for developing creativity (Felder et al. 2000). Reflection-in-action is learning by doing Schon (1983) which is important in engineering and other disciplines. Students need the opportunity to practice skills before they are assessed. Furthermore, experiential learning provides their students options to select assignments and promotes deeper learning.

The method of teaching creativity to engineering students has also been a key concern (Salter and Gann 2003). Engineering is essentially a creative topic that can be taught (Velegol 2014). Engineering creativity specifically encompasses problem finding and problem solving. However, problem finding has not been a major focus of engineering education. According to Nickerson (1999), creative problem finding offers another avenue for increasing creative production in engineering. Problem finding is common for an engineering designer who needs to think about and solve unforeseen problems (Ferguson 1992). An engineer's imagination and creativity have the power to develop technological solutions to problems (Deal 2001). Solutions can be achieved through both problem finding and problem solving.

7.5 Central Themes Specific to Engineering Creativity

Central themes specific to engineering creativity include Originality (novelty) (Shah et al. 2003; Thompson and Lordan 1999; Weisberg 1999) and Usefulness (applicability) (Larson et al. 1999; Shah et al. 2003; Thompson and Lordan 1999). Engineers not only need to address aesthetics—like artists, but they also need to solve problems, prevent potential problems, and address utility within the constraints and parameters that have been designated. Furthermore, a creative aspect of engineering has been described as "functional creativity" (Cropley and Cropley 2005).

Functional creativity means that products designed by engineers typically serve a functional and useful purpose, unlike fine art. Creative products emphasize novelty, resolution, elaboration, and synthesis (Cropley and Cropley 2005). Building on this, problem finding may offer another avenue for increasing creative production (Nickerson 1999). Problem finding is a skill often found in art, yet is also necessary in science and engineering. Both problem finding and problem solving are relevant to an engineer's creativity; however, both attributes have not been measured in much depth in engineering creativity specifically. These attributes need to be assessed and further developed by educational activities (Cropley and Cropley 2005).

7.6 Measurement Needs for Engineering Creativity

The need for creativity in engineering has led to the development of numerous creativity support tools to enhance the creative design process (Baillie and Walker 1998). These tools not only address technology for the creative process, but also include measurement for assessment. However, to date, previous measures of engineering creativity have been limited. According to the literature available, only a few measures were developed to assess creative abilities in engineering design. These include the Owens Creativity Test (1960) and the Purdue Creativity Test (1960).

7.6.1 Engineering Creativity Measures

7.6.1.1 Owens Creativity Test (1960)

The Owens Creativity Test (Owens 1960) was developed to assess mechanical engineering design. Test takers list possible solutions to mechanical problems (divergent thinking). Reliability ranged from 0.38 to 0.91, while validity ranged from 0.60 to 0.72. Validity was determined via the testing of the engineers in mechanically related occupations. This assessment tool is out of print and is no longer used.

7.6.1.2 Purdue Creativity Test (PCT) (1959, 1960)

The Purdue Creativity Test (PCT) was developed by Lawshe and Harris (1960) as an engineering personnel test, as a method for identifying creative engineers and their occupational potential. Participants are instructed to list as many possible uses for one or two shapes that are provided. The PCT has adequate reliability (0.86 to 0.95) and modest validity (29–73 % for low scorers and high scorers, respectively). Validity was determined by assessing professional engineers (process and product engineers) working in industry. Participants are instructed to generate original and novel possible uses for single objects or pairs of objects. Scoring is based on Fluency (number of uses) and Flexibility (differing categories of uses).

Although a reliable and valid measure, limitations include little use in field of engineering. This assessment measures engineering creativity only by assessing Fluency (number of responses) and Flexibility (categories of responses) and does not directly assess Originality. Both the Owens Creativity Test and the Purdue Creativity Test are limited in that they only measure divergent thinking (generating different solutions to a problem) by asking participants to list potential uses.

7.6.2 Creative Engineering Design Measure

7.6.2.1 Creative Engineering Design Assessment (CEDA) (2008, 2011)

The Creative Engineering Design Assessment (CEDA) offers a new method for assessing creative engineering design. Participants are asked to sketch designs that incorporate one or several three-dimensional objects, list potential users (people), as well as perform problem finding (generate alternative uses for their design) and problem solving in response to specific functional goals. Sketching is instrumental in design problem solving (Goldschmidt and Smolkov 2006) and results in creative solutions. Some speculate that engineers think in pictures (Grandin 2006; B. Gustafson, personal communication, May 25, 2010). The sketching aspect of the CEDA is engineering specific and useful for spatial manipulations that are specifically necessary for engineering design.

Creativity in psychology has traditionally emphasized divergent thinking skills (open-ended multiple solutions to a problem) (Torrance 1974; Guilford 1984). In the CEDA model, convergent science and divergent practices are integrated as necessary functions for creative engineering design. Schon (1983) reported that engineers have become aware of the importance of actual practice that encompasses uncertainty, complexity, and uniqueness in convergent science and divergent practices. Engineering often requires the need to solve problems in these types of ambiguous situations. However, deriving alternative solutions through problem finding is essential. Both *problem solving* (generating the solution) and *problem finding* (identifying potential other problems) are important for creativity in engineering.

In order to be creative in engineering, solving problems is vital; however, determining when there is a problem to solve may be even more important (Ghosh 1993). Creativity support tools have focused on generating possible solutions, but not on identifying new problems (Baillie and Walker 1998). Yet, despite the importance of *problem finding* (identifying current problems or recognizing potential problems that may occur), the literature in engineering has traditionally been meager. This is true for both assessing engineering creativity and problem finding. To date, the Creative Engineering Design Assessment (CEDA) is one of the only tools to date that assesses both *problem solving* and *problem finding* (Charyton et al. 2008).

The CEDA builds on and improves upon features of the Purdue Creativity Test (Lawshe and Harris 1960) as well as Guilford's (1984) model of divergent thinking in that the questions are open-ended. The CEDA also assesses Fluency (number of ideas), Flexibility (categories of ideas, types of ideas, grouping of ideas), and Originality (new ideas, novelty). However, the CEDA differs from the Purdue Creativity Test in that it was not designed solely as a divergent thinking test. Furthermore, the CEDA was developed to specifically measure creativity unique to engineering design. Design is crucial for creativity and innovation for *users* and customers (Cockton 2008). Furthermore, participants sketch their own designs. Jordan and Pereira (2009) found that sketching was valuable for teaching engineering design. The CEDA has been demonstrated to be specifically related to engineering creativity and spatial skills while measuring aspects that are unique to engineering design.

Engineering creativity involves both *convergent thinking* (generating one correct answer) and *divergent thinking* (generating multiple responses or answers) (Charyton et al. 2008; Charyton and Merrill 2009). In the CEDA, students are asked to generate up to two novel designs to fulfill a generalized goal. The rationale for this limit is to work within the time *constraints* of the test and to elicit higher-quality responses. Also, because there are five steps to each design, the process requires more elements than just listing uses. In the CEDA, *divergent thinking* is assessed by generating multiple solutions. *Convergent thinking* is assessed by solving the problem posed. *Constraint satisfaction* is assessed by complying with the parameters of the directions and also adding additional *materials* and manipulating the objects as desired. *Problem finding* (identifying other potential problems) is assessed by identifying *other uses* for the design. *Problem solving* (finding a solution to a specific problem) is assessed by deriving a novel design to *solve the problem* posed.

Unlike previous measures, the revised CEDA also measures Originality and Usefulness, which, to date, is a unique component when compared to other general creativity and engineering creativity measures.

7.7 Current Measurement Contributions: The CEDA (Creative Engineering Design Assessment)

7.7.1 Theoretical Framework of the CEDA

Figure 7.1 describes how each item on the CEDA addresses these theoretical constructs. *Divergent thinking* is assessed by generating multiple solutions to the problem. *Convergent thinking* is assessed by solving the problem posed by creating at least three designs for three problems. *Constraint satisfaction* is assessed by complying with the parameters of the directions and also adding additional materials and manipulating the objects as desired. *Problem finding* is assessed by identifying other uses for the design. *Problem solving* is assessed by deriving a novel design to solve the problem posed. This means solving the problem appropriately yet in a novel manner.

A readability and comprehension analysis was conducted on the CEDA to determine the appropriateness for college students. The analysis measure known

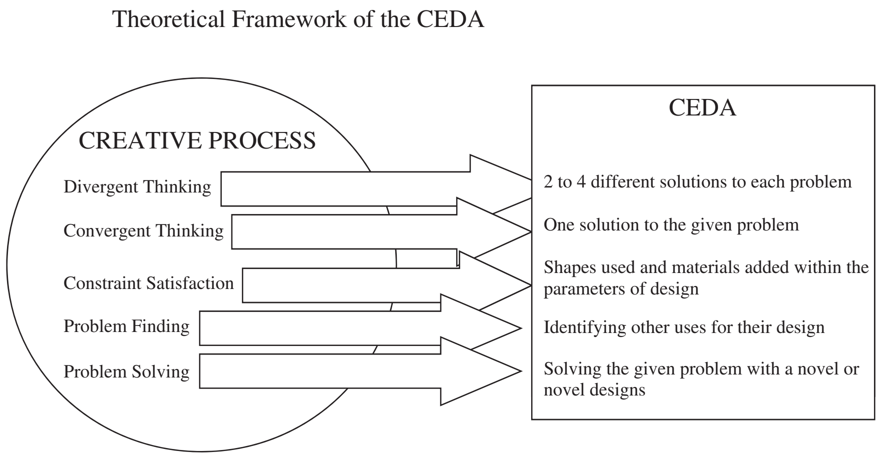

Fig. 7.1 Creative Engineering Design Assessment meta-cognitive processes measured

as the Simple Measure of Gobbledygook (SMOG) (McLaughlin 1969), an online program, http://www.harrymclaughlin.com/SMOG.htm, was used to assess the reading and comprehension level of the CEDA. The SMOG is designed for evaluating the reading level of materials that can be read independently by a person without assistance from a teacher or instructor (Richardson and Morgan 1990). Readability is recommended at the 6–8th grade level for educational materials for the general public. The SMOG Grade for the CEDA was 8.81, being the 8th grade level, equivalent to a junior high school, which relates to a newspaper reading comprehension level. Therefore, the CEDA would also be appropriate and useful for precollege students at the junior high and high school levels.

7.7.2 Components of Scoring

Figure 7.2 depicts the correlations among the components of the CEDA. The strong correlation ($r = 0.86$) between Fluency (number of ideas) and Flexibility (types of categories of ideas) reflects that both measure divergent thinking in terms of number of designs, although Flexibility uses more categorical analysis. Given this greater abstraction for Flexibility, it is perhaps not surprising that its correlations with Originality (novelty of ideas) ($r = 0.58$) and Usefulness (practicality for potential or current uses as well as number of potential uses) ($r = 0.46$) are numerically higher than those for Fluency ($r = 0.46$ and $r = 0.39$, respectively). The relatively high correlation between Originality (new ideas) and Usefulness (practicality) ($r = 0.65$) is perhaps surprising, given that these are distinct constructs that are both central to engineering creativity. However, their relationship may be higher in an engineering population, which values both Originality and Usefulness more than other fields or domains.

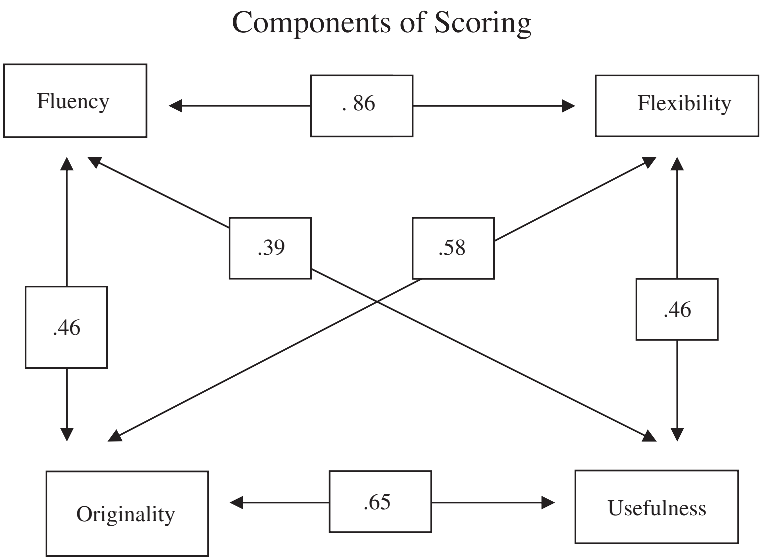

Fig. 7.2 Correlations among the components assessed within the creative engineering design assessment (CEDA). Fluency is the amount of responses. Flexibility is the amount of types or categories of the responses per problem. Originality is novelty or new ideas that are assessed based on a rubric consisting of descriptors and numbers on a scale from 0 to 10. Usefulness is the practicality of the design for current and/or potential future uses on a Likert scale from 0 to 4

The inter-rater reliabilities between the four engineering judges and the one psychology judge were calculated for each of the components, except Fluency, which simply consisted of a count of items. The reliabilities for Flexibility ($r = 0.83$, $p < 0.01$), Originality ($r = 0.59$, $p < 0.01$), and Usefulness ($r = 0.46$, $p < 0.01$) were lower than the inter-rater reliability of the overall CEDA scores without Usefulness ($r = 0.92$, $p < 0.01$) and with Usefulness included ($r = 0.81$, $p < 0.01$). The magnitude of the reliabilities indicates the difficulty of judging Originality and Usefulness. The higher reliability of the overall CEDA scores is based on a combination of these component measures. The CEDA is comparable to the PCT on Fluency and Flexibility.

7.7.3 Properties of the CEDA

7.7.3.1 Reliability (Continued)

Previous correlations among the CEDA scores of two judges were conducted to identify their relationships with each other and establish reliability. Judges were in agreement ($r = 0.98$) with their overall scoring. Inter-rater reliability was high for Flexibility ($r = 0.90$ and $r = 0.98$) and Originality ($r = 0.80$ and

$r = 0.85$), indicating consistency in both test and retest measures, respectively (Charyton and Merrill 2009). The CEDA was consistent for the test and retest reliability ($r = 0.56$) like the other general creativity measures such as the Creative Personality Scale (CPS) ($r = 0.57$), Creative Temperament Scale (CT) ($r = 0.51$), and Cognitive Risk Tolerance Scale (CRT) ($r = 0.43$), $p < 0.01$, for all comparisons (Charyton and Merrill 2009).

Reliability was important to reestablish since we modified the CEDA to assess Usefulness in addition to Originality. The four engineering judges were in agreement with the psychology judge at the following levels ($r = 0.95$), ($r = 0.88$), ($r = 0.91$), and ($r = 0.93$), $p < 0.01$, for all comparisons (Charyton et al. 2011).

7.7.4 Validity

7.7.4.1 Discriminant Validity

In a previous study, Charyton and Snelbecker (2007) found that a music improvisation creativity measure was not related to general creativity constructs (CPS, CT, CRT), yet the Purdue Creativity Test (PCT) demonstrated a modest relationship with these general creativity measures. The CEDA demonstrated discriminant validity from these other general creativity measures (Charyton et al. 2008), like the domain-specific music improvisation creativity measure had in previous studies (Charyton 2005, 2008; Charyton and Snelbecker 2007). The general creativity measures are described as follows:

7.7.5 General Creativity Measures

CPS: *Creative Personality Scale*. The Creativity Personality Scale (CPS) of the Adjective Checklist (ACL) (Gough 1979) was previously administered to assess creativity attributes. According to Gough (1979), aesthetic dispositions are related to creative potential. This instrument was designed as an appraisal of the self. This test was selected because it is highly regarded, reliable, and widely used as a general creativity test (Plucker and Renzulli 1999; Oldham and Cummings 1996).

CT: Creative Temperament Scale. The Creative Temperament Scale (Gough 1992) was adapted from the California Psychological Inventory (CPI), which was designed to assess personality characteristics and predict what people will say and do in specific contexts. Gough (1992) suggested that this measure is capable of forecasting creative attainment in various domains, both within and outside of psychology. Any domain requires skills specific to the domain, yet this measure assesses general personality qualities cutting across disciplines. The Creative Temperament Scale is one of the special-purpose scales of the CPI.

CRT: Cognitive Risk Tolerance Survey. The Cognitive Risk Tolerance Survey (Snelbecker, G. E., McConologue, T., & Feldman, J. M. (2001). *Cognitive risk tolerance survey.* Unpublished manuscript.) consists of 35 self-report items to assess an individual's ability to formulate and express one's ideas despite potential opposition. Responses are on a Likert scale ranging from 0 (very strongly disagree) to 9 (very strongly agree). Higher scores indicate higher levels of cognitive risk tolerance. The Cognitive Risk Tolerance Survey was developed as an extension of an earlier risk tolerance model developed by Snelbecker et al. (1989, 1990). Charyton and Snelbecker (2007a) found that the CRT measure was moderately correlated with the CPS ($r = 0.36$, $p < 0.01$) and CT ($r = 0.34$, $p < 0.01$), which were moderately related to each other ($r = 0.35$, $p < 0.01$). Cognitive risk tolerance may be a component of general creativity that is moderately related to, yet different from, other general creativity measures. This measure was selected as a distinct component of general creativity.

Discriminant validity for the CEDA was established with general creativity measures, respectively ($r = -0.01$ (CPS), $r = -0.13$ (CT), $r = -0.19$ (CRT), $p > 0.05$), suggesting that the CEDA is domain specific to engineering.

7.7.5.1 Convergent Validity

Correlations between the CEDA and other engineering creativity and spatial measures were conducted to establish convergent validity. The CEDA was moderately correlated with the PCT ($r = 0.39$, $p < 0.01$) and slightly correlated with the Purdue Visualization Spatial Test–Rotations (PVST-R) ($r = 0.19$, $p < 0.05$). The CEDA, including Usefulness in the formula of assessment, demonstrated similar results. The CEDA with Usefulness was moderately correlated with the PCT ($r = 0.31$, $p < 0.01$) and slightly correlated with the PVST-R ($r = 0.21$, $p < 0.05$). These findings suggest that creative engineering design overlaps with spatial skills. This finding is logical since sketching requires spatial skills. Furthermore, in the CEDA, participants are instructed to manipulate the objects in any manner they desire without replication. In the PVST-R, participants are instructed to rotate the objects.

The relationship among the variables is consistent with the previous (or initial) CEDA scoring formula and the revised CEDA scoring formula. Figure 7.3 depicts the initial CEDA scoring and the revised CEDA scoring (new CEDA scoring in parentheses) that includes Usefulness. Other domain-specific engineering-specific measures are moderately related to the CEDA, demonstrating that the CEDA is more like other engineering creativity measures (PCT) and engineering spatial measures (PVST-R). Both are domain specific to engineering. This contrasts with previous findings, demonstrating that the CEDA was not like other general creativity measures. Thus, by directly assessing Originality and Usefulness, the CEDA assesses creativity as a well-accepted standardized definition that is also domain specific to engineering (Charyton et al. 2011).

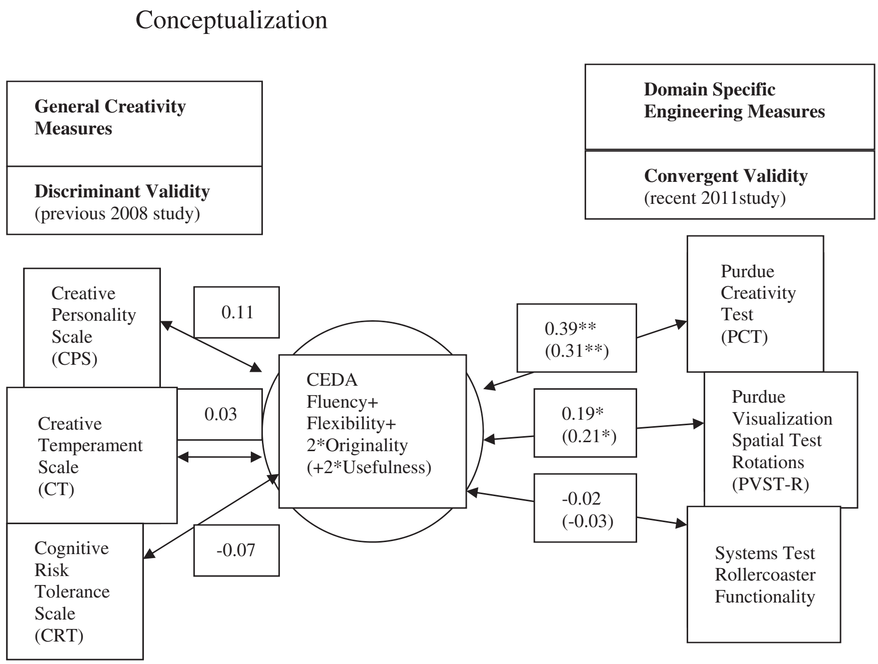

Fig. 7.3 Conceptualization of the relationship of the Creative Engineering Design Assessment (CEDA) with general creativity measures (previous study 2008) and domain specific engineering measures (recent study 2011). The *top left* portion of the figure is based on previous research (Charyton et al. 2008), and the *top right* portion is based on current data in this study with the original and revised CEDA scoring formula. The revised scoring CEDA formula is in parentheses. The correlations for the revised formula with Usefulness (2*Usefulness added to the original CEDA formula) illustrates similar findings with the new scoring of the revised CEDA compared to the previous scoring method without Usefulness. ** indicates statistical significance at the 0.01 level * indicates statistical significance at the 0.05 level

7.7.6 Engineering Measures

PSVT-R: The Purdue Spatial Visualization Test–Rotations. The Purdue Spatial Visualization Test–Rotations is the most common test of engineering students' spatial visualization (Carteret al. 1987). The PSVT-R consists of 30 unfamiliar objects that the observer mentally rotates and has been used for first-year engineering programs (Bodner and Guay 1997). The PSVT-R was devised to test spatial development while minimizing analytic processing (Guay 1980). Using lines and symbols to represent thoughts and ideas of engineers can be more effective than purely verbal descriptions (Scribner and Anderson 2005). The PSVT-R correlated significantly with participants' scores on spatial tasks (Kovac 1989). Males have previously performed better on PSVT questions than females (Guay 1978; Kinsey et al. 2007); however, the two genders scored equally on self-efficacy (belief in their own capabilities in order to accomplish the task), while upper-class students scored higher on both (Kinsey et al. 2007). The PSVT-R is often administered to freshmen with a course objective of assessing the spatial skills needed to succeed in subsequent engineering design graphics courses (Sorby and Baartmans 1996).

The PSVT-R has high construct validity for spatial visualization ability (Branoff 2000; Guay 1980). Guay reports internal consistency (reliability) (Kuder Richardson $r = 0.87$, 0.89, and 0.92) from 217 university students, 51 skilled machinists, and 101 university students, respectively (Guay 1980). Other studies also report high reliability (Kuder Richardson $r = 0.80$ or higher) (Branoff 2000; Scribner and Anderson 2005). Based on these analyses, most researchers agree that the PSVT is a good measure of spatial ability (Branoff 2000; Yue and Chen 2001).

The CEDA is useful for assessing creativity in Science, Technology, Engineering and Mathematics (STEM). Constructs such as general creativity and cognitive risk tolerance can also be assessed in STEM disciplines (Charyton and Snelbecker 2007; Charyton et al. 2011). These dimensions may contribute toward a richer understanding of creative design specific to engineering.

7.8 Importance of Creative Engineering Design to STEM (Science, Technology, Engineering and Mathematics) Prevails

"Our country's economic competitiveness and prosperity depend on innovative STEM-educated young people that work together to solve our problems effectively and creatively" (Brower et al. 2007). According to these authors, educators need to engage at least 70 % of the student population not just the top 10 % of students. Students entering STEM are a current vital need, not only for our country, but for many countries. If students are taught that engineering can be fun through creative design, this could potentially engage more students to pursue engineering and may result in increased recruitment and retention in the colleges of engineering.

Highly creative people redefine problems, analyze ideas, persuade others, and take reasonable risks to help generate ideas (Sternberg 2001). Creativity is certainly among the most important human activity that provides conveniences and products of human inventiveness (Simonton 2000). Despite its importance to society, creativity has received relatively little attention in psychology compared to other research topics (Feist 1999; Sternberg and Lubart 1999). Although people have been engaged for centuries in creativity, only in the past few decades has this process been considered capable of analysis and improvement (Soibelman and Peña-Mora 2000). More recently, there is growing interest and need for creativity in the sciences.

Currently, creativity and critical thinking skills are incorporated into the core mission statement of many universities, educational programs, and college curriculum. However, few institutions utilize an empirical method of evaluating creativity. The published literature also suggests that creativity is likely domain specific (Kaufman and Baer 2005). Even in similar science or STEM areas such as engineering and chemistry—creativity may be expressed specifically and uniquely in each area.

7.9 Creativity for Increasing Enrollment in STEM

Creative design and its measurement may act as a catalyst to increase enrollment in STEM. Exposure to engineering and the CEDA may likely take place in universities, colleges, community colleges, institutes, academies, high schools, and junior high schools. The CEDA was developed to measure creative engineering design in adolescent students. In regard to "gifted" children, if the child is reading at the 8th grade level, then the CEDA may also be appropriate at younger chronological ages.

Creating an interest in STEM has become the new frontier (Harriger et al. 2008). Competitive degree programs require creativity and innovation (Harriger et al. 2008). STEM interests can also be heightened by establishing the relationship between creative and performing arts with broader STEM concepts (Reflections and Measures of STEM Teaching and Learning on K-12 Creative and Performing Arts Students). Harriger (2008) suggests that designing rock guitars was successful for engaging high school students. The CEDA includes a problem to create designs that produce sound that could be useful in early STEM curricula.

Creativity is also a universal application of innovativeness that does not show favoritism toward race or ethnic boundary (Riffe 1985) nor gender. Underrepresented students' interests and performance are needed to foster skills that are prerequisites for STEM careers (Verma 2011). The CEDA has been administered to men and women of various racial and ethnic backgrounds and is suitable for diverse populations.

Since 2005, the USA has been following with job creation (at 11th in the world) (Ireland, Belgium, and Australia are the top three, respectively); however, it has been leading with innovation and the global economy (#1 in the world) (Florida 2005). Through prioritizing creativity and innovation, as we did with prioritizing scientific creativity in the 1950s, we can enhance global prosperity, not only for the USA but also for other countries. Creativity is needed, even more, especially due to our current global and societal problems. Creativity and innovation are primarily relevant today in our current global economy and societal concerns.

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Chapter 8
The Impact of Improvisation on Creativity: A Fractal Approach

Christine Charyton

Abstract This is an investigation of musical creativity. Improvisation is a complex system for understanding musical creativity. Improvisation is often expressed through jazz music. This chapter focuses on the measurement of jazz improvisation in order to better understand musical creativity. The science and art of music analysis are discussed. Improvisation can be a measure for musical creativity; however, there are limitations with existing measurement methods. Instead, fractal analysis offers an approach that addresses such limitations. In a case study approach, the work of John Coltrane and his relevant biographical events are discussed along with a fractal analysis examining the sequential structure of pitches in his saxophone solos. Saxophone solos were transcribed from sheet music into a format that represents an absolute pitch numerically. The pitch sequences were examined using power spectral analysis. Results indicate that all 18 Coltrane saxophone solos display sequences of successive pitches that are consistent with anti-persistent fractional Brownian motion having $1/f^{\alpha}$ power spectra with scaling exponent α between 1.6 and 1.8. Brownian motion is a type of statistical pattern that is symptomatic of self-similar or fractal patterning across time (Mandelbrot 1998). In addition, average mutual information analyses revealed various dominant regular rhythmic patterns in several of the pieces. Eighth-note patterns were dominant in his earlier work, while greater irregularity was present in rhythmic patterns of his later work. Thus, Coltrane's improvised solos, including his later avant-garde compositions, are comprised of Brownian fractal patterns, which others using a different pitch encoding technique have previously identified in performances of both classical and jazz music (e.g., Boon and Delcroly 1995). These fractal patterns quantify the concepts of order and complexity addressed in the Birkhoff's Theory of Aesthetic Value. Fractal analysis offers another approach toward understanding the dynamics of improvisation and musical creativity.

C. Charyton (✉)
Ohio State University Wexner Medical Center, Columbus, OH 43210, United States
e-mail: charyton.1@osu.edu; Christine.Charyton@osumc.edu

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8.1 Musical Creativity

The relationship between psychology and music with mathematics is a growing and important area, not only in aesthetics, but also in music and psychology. Music is believed to communicate feelings of the composer while arousing sympathy and empathy in the auditor (Langer 1951). Music is a symbolic, true language of feeling. Creativity depends on the individual's ability to move beyond the death and life instinct (May 1975; McGlashan 1987).

Church music was developed historically as a need to find appropriate pitch intervals to praise God. McGlashan (1987) restated the importance of mathematics in music geared toward perfection. He stated that God was not a musician, but music was used to praise God, in proper mode. Pythagoras, the mathematician, assisted with the pioneering of the arithmetic pitch intervals now used in music therapy (Cheshire 1996). Science and art somewhat overlap as interests of individuals. In music, Poincare unsuccessfully tried to learn the piano, while Einstein was more moderately successful at playing the violin (Miller 1992). All human beings possess some degree of creative potentiality (Alterhaug 2004).

8.2 The Nature of Improvisation

The nature of jazz improvisation can be seen as spontaneous, unrehearsed ideas where musicians seek to create their own learning, creative opportunity (Alterhaug 2004). Improvisation is the vehicle for the expression of creativity from intuition, consciousness, and synchronicity (Pressing 1994). Improvisation offers the performer the opportunity to freely express their own creativity (Aitken 1976). The word "improvisation" has not been used in the musical society until the 1850s and was often used as rhetoric training (Alterhaug 2004). Improvisation is characterized to have a longer history than written music and has appeared in all kinds of music throughout history to have an impact on many different genres of music. Improvisation differs with traditional classical music in that there is more free form of personal expression and improvisation that is not as rigid and limiting as classical music. Musicians are expected to create something that is new and coherent that requires continual experimentation. Aims of musicians can be to integrate ideas, take materials from various sources, and develop their ideas into a new form in order to express their own unique style.

8.3 Improvisation Still Needed in Music Education and Research

Despite advocacy for creativity and music improvisation skills, improvisation is rarely a part of music education curricula (Azzara 2002). A need persists to create a culture that embraces improvisation, creativity, and risk taking. There is still a need to nurture and design creativity into music teaching (Webster 1990a; Webster and Hickey 2001). Both psychologists and music educators contribute to this line of research (Webster 1990b). Expert teachers need to focus on creative thinking in their music teaching (Webster 1994). Improvisation is highly related to creativity (Johnson-Laird 2002). Creativity is vital within the context of completing education in music (Running 2010). However, jazz improvisation is a creative act of self-expression that still cannot easily be evaluated (Burnsed and Price 1984).

Research in the field of creativity has been focused more toward the individuals in the twentieth century; societal shifting has changed perspectives on learning regarding forms of musical expression and new aspects of human interactions as well as communication (Johnson-Laird 2002). Improvisation sheds light on creative action that focuses on balancing between structure and flexibility within the activity (Alterhaug 2004). Learning outcomes are more for the creative process than the product. The necessity of improvisation has rarely been recognized in different organizational contexts such as industry, management, and education. Communicating in improvisation can lead to releasing positive energy, activating knowledge and reflection (Alterhaug 2004). Additionally, trust and freedom can also be associated with improvisation, two secure elements of social dynamics. Improvisation can lead to positive development of personality and give support to creative processes that are cognitive and conscious, while enhancing our understanding of human communication (Alterhaug 2004; Johnson-Laird 2002). There have been questions of whether improvisation and creativity can be computable based on algorithm; creativity may pose a central algorithmic demand of computational power between creating chord sequences and creating melodic improvisation in real time (Johnson-Laird 2002). Additional research is still needed for the construction of jazz achievement rating scales with more dimensions (Pfenninger 1990).

8.4 The Measurement of Improvisation and Creativity

A critical issue is the evaluation of improvisational abilities (May 2003). The number of performers and pieces of music studied is small for improvisational studies and their measurement (Gabrielsson 2003). "This may be due to differences in types of music, instruments used, differences among performers, stylistic conventions, measurement procedures, data analysis and other factors" (Gabrielsson 2003, p. 550).

Yet "…improvisation began to sustain the serious interest of music educators and psychologists, primarily under the guise of creativity, near the middle of the century" (Gordon 2000, p. 5). Musical imagery suggests a figurative picture of what each sound represents. Musical imagery does not require the assimilation and comprehension of sound as audiation does. Imitation, memory, and recognition are part of the audiation process. Audiation has only become professional vocabulary in as little as approximately 20 years ago. Audiation describes the process of applying intrinsic meaning to music for which the sound is no longer physically present or may never have been physically present at all (Gordon 2000).

8.4.1 Observer Ratings

Studies aimed at evaluating jazz improvisation which used a series of 3 to 8 judges to evaluate improvisation abilities in efforts for valid objective evaluation of improvisational achievement (Burnsed and Price 1984; May 2003). For example, saxophone auditions may be judged in relation to harmony, originality, flexibility of tone, variety of rhythms and jazz nuances (May 2003), and harmonic rhythmic quality (Guilbault 2009). Gordon (1984) stated that rating scales are important for teacher-made tests for measuring jazz improvisation achievement. Improvisation instructors can construct objective measurement of jazz improvisation achievement for individual needs and instruction (Shilling 1987). Azarra et al. (1997) have a systematic learning method for the teaching of improvisation. In jazz improvisation evaluation scale items, creative development is specific to musical expressiveness, creativity, and style (Smith 2009). These factors have a relationship with skill level. Aitken (1976) offers self-instructional methods for improvising on the trumpet consisting of 112 lessons to enhance aural and technical skills for self-instruction, but lacks empirical validation.

8.4.2 Self-report Measures

Other measures have been developed to assess improvisational abilities. Rubrics offer a mechanism for assessing higher-order thinking as well as levels of achievement (Wesoloski 2013). The improvisation readiness test contains 25 items that require a yes or no response to gage one's comfort level and confidence with improvisation (Little 1976). This measure has no empirical reliability and validity data available. Little's measure has also not been used much. McDaniel (1974) developed the *McDaniel Background Inventory* (*MBI*) to assess music achievement, music experience, and improvisational ability with 131 items reduced to 29 items that are a multiple-choice response test. T test, chi-squared, and discriminant analyses indicate sufficient differences and goodness of fit for jazz improviser musicians (college musicians who improvise through jazz music) compared to non-improviser musicians (college musicians who do not improvise, but were still chosen from concert band, choir, or school orchestra). The MBI has not been widely used and does not have thorough reliability and validity reports.

8.4.3 Objective Standardized Measures

The harmonic improvisation readiness record or HIRR is a paper and pencil test designed by Edwin Gordon for students grades three and above (Gordon 1998). Its purpose was to determine a student's ability to audiate harmonic patterns and predict a student's potential (aptitude) to improvise harmonically. Gordon (2000) stated that "success in harmonic improvisation depends on…the ability to audiate harmonic patterns and progressions and the ability to audiate in a temporal sense, when the chord changes take place" (p. 33). "…These unique functions of audiation could actually alter our traditional ways of thinking about musical aptitude itself" (Gordon 2000, p. 5). Gordon (2012) suggests that persons with high improvisational abilities can distinguish between scales and tones easier. Westervelt (2001) suggested that the HIRR was helpful in assessing audiation in relation to improvisation readiness.

This instrument has been judged as an appropriate measure for college students (Gordon 1998). Students are asked to listen to two musical examples and determine whether the musical examples were the same (S) or not the same (NS). A third option was offered being unsure or don't know (?). The HIRR is a 17 min recorded group test consisting of 43 pairs of harmonic items performed in various tonalities. Test instructions, practice items, and test items were played via a CD recording (Gordon 1998). Subjects mark their answers on a standardized answer sheet as devised by Edwin Gordon. Each subject filled in a circle to indicate whether the two samples in each item were the same (S), not the same (NS), or unsure (?). Means, standard deviations, standard errors, reliability coefficients (split-halves and Kuder–Richardson), item difficulty, and item discrimination levels were reported in the test manual. Item difficulty ranges from 0.85 to 0.20 for the HIRR. The smaller the number, the higher the difficulty, meaning less of a percentage responded correctly to the item.

Difficulty and discrimination are 0.72 and 0.37, respectively, in college students as compared to 0.76 and 0.35, respectively, for grades 4–12. The data on a pilot study at Temple University by the researcher obtained in testing undergraduate education college students support Gordon's theory that older students score slightly higher (Charyton, 2001, An investigation of readiness in undergraduate college student education majors to improvise harmonically, Temple University at Philadelphia, Unpublished). These college students tested on the Harmonic Improvisation Readiness Record received item difficulty ranges from 0.90 to 0.29. The higher the difficulty, the easier the item. For example, a 0.60 difficulty item indicates that 60 % of the students answered that item correctly. The standard error of measurement for the HIRR is 2.4 (Gordon 1998). Results of the HIRR in a randomized sample indicate 23.5 % of variance. The standard error of measurement for the HIRR is 2.4 (Gordon 1998). Results of the HIRR in a randomized sample indicate that 23.5 % of variance. The HIRR and RIRR are currently listed in the Buros Mental Measurements Yearbook but have not been reviewed yet to date.

8.5 Reliability and Validity of the HIRR

Research by Gordon administered the Harmonic Improvisation Readiness Record (HIRR) and Rhythmic Improvisation Readiness Record (RIRR) to grades 3–12 as well as university students. Reliability coefficients for the HIRR ranged from 0.86 to 0.83 from grade 3 to grade 12 (Gordon 1998). Scores on the HIRR are slightly more reliable for older than younger students. Music aptitude tests generally have less specificity than music achievement tests; thus, a music aptitude test may be expected to be less reliable than a music achievement test (Gordon 1997).

The mean of the HIRR was 28.9 with a 5.01 standard deviation for senior high school (Gordon 1998). Overall, regardless of chronological age, HIRR mean (28.6) and standard deviation (5.60) were calculated to remain stable. However, the mean is higher for undergraduate college students in comparison with the means of high school, middle school, and elementary school students as data obtained by Edwin Gordon in the Harmonic Improvisation Readiness Record and Rhythmic Improvisation Readiness Record test manual.

Gordon (1998) stated that content validity and construct validity are important types of subjective validity for the HIRR and RIRR. Correlations were also performed with other Gordon tests. More specifically, the RIRR (0.73) was more highly related than the HIRR (0.45) to the students' recorded improvisations (Gordon 2000). These numbers represent the validity of the instrument (E. Gordon, personal communication, June 28, 2003).

"Types of statistical evidence of validity and reliability, item difficulty and discrimination indexes, means, standard deviations, score distributions, and the correlation of test scores with other criteria, such as teachers' ratings or grades, scores on related tests, and future success" (Gordon 1998, p. 54). "All of these data are desirable because each contributes unique information about overall validity" (Gordon 1998, p. 54). According to Gordon, "Both [the HIRR and RIRR] are dependable and valid" (E. Gordon, personal communication, June 28, 2003). The "…HIRR and RIRR have some characteristics of both music aptitude tests and music achievement tests and other characteristics that are unrelated to either type of test" (Gordon 1998, p. 13). Scores on music aptitude and music achievement change as students get older which is not the case with the HIRR and RIRR (Gordon 1998).

However, paper and pencil tests may be more difficult to administer on eminent musicians, especially if they already passed away. Therefore, fractal analysis on improvisational solos may offer another avenue for understanding the complexity of improvisation and creativity. Researchers have gained a deeper understanding of the complexity of music improvisation through fractal analysis. The rest of this chapter will focus on fractal analysis of the improvisational work of jazz legend John Coltrane.

8.6 Improvisation, Creativity, and the Case Study: John Coltrane

Case studies can illustrate the depth of highly creative achievement (Gardner 1993). Some researchers suggest that specific conditions lead to high levels of creativity within individuals (Simonton 1984; Sternberg 1999). Creativity can be developed through practice and perseverance. Davison (2010) suggested that improvisational training may affect performer's self-perceived ability for overall performance. Self-efficacy for music may help with motivation and persistence (Bandura 1986; Davison 2010).

8.7 Creativity, Fractals, and John Coltrane's Saxophone Solos

John Coltrane's approach to style remains elusive, even though the saxophonist is the subject of thousands of books and articles, and his solos have been rendered in over 700 transcriptions by one disciple alone, White (1981, 2006). The "established theory of aesthetic perfection" Ravi Coltrane points to in the liner note comment is related to the mathematics of fractal geometry. Fractal objects (Benoit Mandelbrot coined the term *fractal* in 1975) are comprised of smaller, nested copies of the whole object. These kinds of structures turn up in a surprising range of natural objects and processes such as fern leaves, the silhouette of mountainous landscapes, and the boundaries of cumulus clouds. Relationships between nature, mathematics, and beauty have fascinated theorists since antiquity; Aristotle (1882), Euclid (1803), Newton (1720), and Abbott (1992, 1884), for example, were interested in the philosophy of mathematics, geometry, science, nature, and aesthetics. Beyond patterns in solid structures (the commonplace understanding of geometry), fractal geometry can be applied to patterns that unfold in time. Application of fractal geometry to temporal sequences has, itself, a long intellectual pedigree. Fourier (1878), Brown (1827), and Mandelbrot (1998) all shared an interest in identifying patterns of motion. Whether describing the fractal structure of a solid object or a pattern developing over time, the pattern most commonly referred to is $1/f$ scaling (pronounced "one-over-ef") or more precisely $1/f^{\alpha}$, where α is a scaling exponent. Similarly, temporal fractal patterns can be perceived as patterns of occurrence over time that can be revealed by applying the analytic techniques developed by Fourier.

Turning to a selection of John Coltrane's solos, the fractal structure described is a characteristic of the melody that unfolds in each piece. This case study concerns relationships across the successive notes or pitches in the pieces. The patterns identified in the sequences' successive pitches illustrate fractal structure across time. Similar fractal patterns are apparent in the temporal pattern of pitches in Coltrane's solo pieces.

8.7.1 Fractal Analysis of Coltrane's Solo Pieces

Several quantitative and descriptive studies of Coltrane's music have been reported (Aitken 2005; Bair 2003; Weiskopf and Ricker 1991). However, the present analysis is the first to apply methods rooted in fractal geometry to Coltrane's solo saxophone performances in order to better understand the complexity of his technique. There were two main goals of using fractal analysis. The first goal was to examine how fractal geometry could provide a more accurate and quantitative analysis of Coltrane's style. This could be another analysis tool for musicians since a mathematical analysis has strong potential for being less culturally biased by Western traditions. The second goal was to evaluate Birkhoff's Theory of Aesthetic Value (1933) in relation to quantitative fractal analyses of other classical and jazz performances and compare these analyses to this investigation of the improvised solos of one specific performer, namely John Coltrane. Previously, $1/f^{\alpha}$ analyses were applied to patterns of amplitude (or loudness changes) in the sound output and to wave forms of musical performances (Boon and Delcroly 1995; Jeong et al. 1998; Peterscmitt et al. 2001; Voss and Clarke 1975, 1978).

In these analyses, fractal patterns are documented, based on the audio outputs of musical performances that include the sounds generated simultaneously by several musicians. Here, this fractal analysis focuses on a single individual's solo performances that, because they need not take other players' expectations or movements into account nor need they be bound to a score, are more subject to spontaneous improvisation than the orchestral performances characterized in previous studies.

This mathematical analysis, based on Fourier analysis (Fourier 1878), revealed fractal structure in Coltrane's solo pieces in order to better understand the complexity of this music since current musical analyses may be culturally biased in the Western classical tradition. This mathematical analysis using fractal geometry is quantitative to reduce or eliminate any cultural biases. A Fourier analysis approximates any complex waveform as a linear composite of simple, regular sine waves spanning a range of frequencies. Pitch variation can be fully characterized by the amplitudes and phase shifts of these sinusoidal waves as a function of their frequencies of change in pitch.

In this discussion, the emphasis will be on the squares of the amplitudes (amplitude^2) of the sinewaves, or power versus frequency. The mean-squared value or "power" of a sine wave is proportional to its amplitude squared. In the present context, "power" takes on a second meaning as well. A "power law" scaling relation between two variables is a relationship in which one of the two variables is raised to some exponent or "power." The analysis of musical pitch can reveal a power law relationship between the squared amplitudes, or power of the sinewaves used to approximate a pitch sequence and the frequency of the sinewaves. More specifically, power is inversely proportional to frequency f raised to some scaling exponent α, or $1/f^{\alpha}$. If power is proportional to $1/f^{\alpha}$, then the logarithm of power is proportional to the logarithm of frequency multiplied by $-\alpha$; that is, log(power) is proportional to $-\alpha\log(f)$. This linear relationship between the logarithm of power and the logarithm of frequency can be revealed by plotting power versus frequency on double logarithmic axes. The slope of the linear trend is $-\alpha$.

If α is zero (power proportional to $1/f^{0} = 1$, or a constant), the power spectrum describes "white noise." For white noise, each successive value in the time series is unrelated to the previous or subsequent values; it is random and unpredictable. In the context of musical pitches, white noise means the absence of a recognizable melody, as if each successive pitch were drawn from a hat, at random. White noise can be generated by successive tosses of 1 die with 120 sides (Jeong et al. 1998). The resulting series is random and irregular.

A related pattern is referred to as Brownian motion. It is a stochastic process, or a time series which has independent increments and demonstrates self-similarity (Lyuu 2002). Brownian motion was named after Scottish botanist Robert Brown. In June, July, and August 1827, Brown described the structure of plants from various locations around the world as well as sketched their aesthetic beauty. The term, "Brownian motion" was later coined in honor of his discovery. Brown observed that small particles of pollen from plants decomposed in an aqueous solution, visible by microscope, had an irregular motion Honerkamp (1994). Brown's examination of the "*Molecules*" from the grains of pollen adhering to the stigma "particularly in *Antirrhinum majus*, "led to his discovery" (pp. 479).

> Their motion consisting not only of a change of place in the fluid, manifested by alterations in their relative positions, but also not unfrequently of a change of form in the particle itself; a contraction or curvature taking place repeatedly about the middle of one side, accompanied by a corresponding swelling or convexity on the opposite side of the particle. In a few instances, the particle was seen to turn on its longer axis. These motions were such as to satisfy me, after frequently repeated observation, that they arose neither from currents in the fluid, but belonged to the particle itself. (Brown 1827, p. 466–467)

This observation led to quantitative data (Einstein and Infeld 1938) and further scientific understanding in applied mathematics, physics, engineering, and other sciences. Brownian motion or "Brown noise" can be generated by a series from 1 die with 3 sides ($+1$, 0, -1), in which each new toss of the die is added to the sum of the previous tosses (Jeong et al. 1998). The increments are thus independent and random. However, the overall series is more predictable than white noise, with less opportunity for randomization and large sudden changes. Brown noise has a spectral slope of -2 (scaling exponent $\alpha = 2$, power proportional to $1/f^{2}$) and corresponds to a higher degree of consistency of structure from pitch to pitch. Successive pitch values are only small random increments or decrements away from previously played notes. The reason such a sequence is referred to as a motion is because previous pitches serve as the origin for new pitches. The music may sound like a clear pattern of order but with unpredictability demonstrated by fluctuations between pitch increments. Boon and Delcroly (1995) have used the term “red noise” to refer to the $1/f^2$ spectrum that others describe as Brown noise (e.g., Jeong et al. 1998; Schroeder 1990).

Poised in between white noise and Brown noise is pink noise, which has a spectral slope that is approximately -1 (scaling exponent $\alpha = 1$, power proportional to $1/f^1 = 1/f$). Pink noise has been described as a key feature of the “Theory of Aesthetic Value” advanced by Birkhoff (1933) because pink noise power spectra have been considered more pleasing and interesting than either white or Brown noise. Pink noise is complex in the sense that it is self-similar and entails some predictability. However, pink noise is not as predictable as Brown noise nor is it excessively and strictly random. Pink noise is structured with persistent, long-term fluctuations. These fluctuations can be across extensive series, such as unfolding across runs of hundreds of notes, within which are nested even smaller coherent patterns of fluctuations that are correlated. Pink noise is statistically self-similar and has a fractal structure in time. Pink noise can be generated from a series of tosses of a randomly chosen subset of 7 dice from a larger set of 20 dice, each with 6 sides. The sum of the 20 dice determines the next value in the series. Music that resembles pink noise may sound more complex with greater randomness than music that resembles Brown noise. According to Jeong et al. (1998), the variability of a pink series is neither as unpredictable as white noisenor as predictable as Brown noise. White noise, Brown noise, and pink noise are all examples of self-similar fractal structure with power law relationships having different slopes or scaling exponents.

Previously, Voss and Clarke (1978) examined the spectral density of audio power fluctuations in musical pieces such as Scott Joplin piano rags, classical music, rock music, and news and talk radio broadcasts. In each case, they identified a power law scaling relation consistent with pink noise. Voss and Clarke (1975) define $1/f^{\alpha}$ noise with a range from $0.5 < \alpha < 1.5$ as pink noise, a definition that is consistent with other literature describing pink noise (Wagenmakers et al. 2004). Subsequently, Voss and Clarke (1978) demonstrated that additional pieces such as Mario Davidovsky’s *Synchronism I*, *II*, *and III* and Karlheinz Stockenhausen’s *Momente* demonstrated approximately $1/f^1$ spectral densities, while Milton Babbitt’s *String Quartet No. 3*, Betsy Jolas’ *Quatuor III,* and Elliott Carter’s *Piano Concerto in Two Movements* showed decreasing correlations at times longer than several seconds, yet were still demonstrating pink noise. George Birkhoff, writing in 1933, emphasized the importance of sequential order and complexity for aesthetically pleasing music. Citing Voss and Clark (1978), Schroeder (1990) suggested that Birkhoff’s aesthetic value corresponded to $1/f^{\alpha}$ spectra with scaling exponent α between 0 and 2 and falling “right near the middle of this range,” which can be interpreted as being close to a scaling exponent of 1 (Schroeder 1990).

Since then, others have investigated spectral densities from analyses of computer-generated music (Aloupis et al. 2006; Jeong et al. 1998; Pressing 1994), simulated music (Chacón et al. 1992), pitch shift (Cartwright et al. 1999), classical music (Hsu and Hsu 1990, 1991; Hughes et al. 1998), musical output from a jazz ensemble (Peterschmoitt et al. 2001), and classical ensembles (Shi 1995). Boon and Delcroly (1995) analyzed the pitch changes from a musician who played a synthesizer connected to a computer. They found that Mozart's *String Trio KV 266* and *String Trio KV 563 (Divertimento)* along with Bach's *Second Suite for Cello*, *Fugue BWV 870,* and *Musical Offering* had spectral slopes very close to -2 (scaling exponent $\alpha = 2$, power proportional to $1/f^2$), demonstrating Brownian motion. Additionally, Thelonious Monk's "Epistrophy," Bill Evans' "Two Lonely People," and Billy Strayhorn's "Lush Life" also had spectral slopes very close to -2, demonstrating Brownian motion (Boon and Delcroly 1995). These values are not consistent with the range of aesthetically pleasing values suggested by Voss and Clark (1978) or Schroeder (1990). They call into question whether or not pink noise is a common and required characteristic of aesthetically pleasing music.

The examination of Coltrane's transcribed solos is directed at identifying scaling relations between frequency and power in successive pitches through a power spectral analysis. The direct creative product of the improvised performances of John Coltrane (Coan et al. 1995; White 2006) were quantitatively analyzed through a series of fractal analyses and average mutual information analyses in relation to the qualitative musical performances of Coltrane's three stylistic periods from 1959 through 1967. Coltrane expressed his own personal interest in mathematics, the sciences, and aesthetics, an interest that integrated music and elements beyond music. Fractal analysis offers a quantitative approach to characterizing patterns of temporal and spatial (pitch) intervals which are components of music. The analysis of Coltrane's saxophone solos demonstrated spatiotemporal properties in order to better understand his technique with a non-culturally biased mathematical approach.

Of interest is the range of values of the scaling exponent α for Coltrane's music and its relation to the Theory of Aesthetic Value, namely the scaling exponents from Coltrane's earlier improvisations that may be more aesthetically pleasing to many people with Coltrane's later work that was more controversial and considered less aesthetically pleasing. This systematic and numerical comparison of Coltrane's scaling exponents with Birkhoff's Theory of Aesthetic Value and its various interpretations ($0.5 < \alpha < 1.5$). Do the scaling exponents of Coltrane's solos suggest other relations between fractal structure and aesthetics? Namely, if α is outside of the range $0.5 < \alpha < 1.5$, that would indicate a shortcoming of existing interpretations of Birkhoff's theory.

The findings indicate that all eighteen solos from 1959 through 1967 during Coltrane's second, third, and fourth period styles display fractal scaling. These findings suggest that Coltrane's second period was a time with greater predictability and rhythmic emphasis on the eighth note, while later work, especially during the end of Coltrane's fourth period, was less predictable and demonstrated more irregular rhythmic structures. The examination of Coltrane's actual transcribed solos is directed at identifying scaling relations between frequency and power in the pitch sequences represented as numerical semitones. Coltrane's style tends to display $1/f^{\alpha}$ series that have scaling exponents α in the approximate range from

$1.6 < \alpha < 1.8$ (see Table 8.1 and Figs. 8.1, 8.2, 8.3, 8.4, 8.5, 8.6). These results cannot readily be compared with previous analyses of musical power spectra because of the large methodological differences, e.g., pitch sequences in notated solos versus the audio power of music played by multiple instruments. Other classical and jazz music not using transcribed solos, but using performances by a musician using a synthesizer connected to a computer, had spectral slope scaling exponents α in the approximate range from $1.8 < \alpha < 2.2$ (Boon and Delcroly 1995). Further research is needed to compare the solos of Coltrane with the solos of other composers and performers using this fractal method.

Coltrane developed his abilities as a musician by learning songs from scores, by mastering typical scales and their permutations, and through learning tunes by ear—all standard jazz pedagogical practices. Coltrane had also taken an interest in many styles of music, which was reflected through his interest in Stravinsky's *Rite of Spring* (*Le Sacre du Printemps*), *Concerto in E-flat for Chamber Orchestra* ("*Dumbarton Oaks*"), and *Firebird Suite* and Ravel's *Daphnis et Chloé* (Fraim 1996; Ratliff 2007). He also chose rare books of scales to expand his knowledge and command of the instrument (Porter 1998). Coltrane used advanced harmonizing techniques as seen in nonatonic systems (having 9 of 12 pitch classes in a chromatic division of the octave) in "Giant Steps," "26-2," and "Countdown" (Santa 2003) and "exotic" scales from different ethnic cultures to create his own scales, such as "India," "Africa," and "Olé" (Porter 1998).

Coltrane endures as one of the most respected jazz musicians by numerous contemporary jazz and rock musicians (Kofsky 1998; Nisenson 1995; Porter 1998); fractal geometry offers additional insight regarding the dimensionality and complexity of his music. In the short span of Coltrane's career and musical output, he recorded hundreds of compositions and released 35 albums as leader or coleader; many are considered jazz standards (Fujioka et al. 1995). Some albums, although less accepted at the time, such as *Giant Steps* and *My Favorite Things*, are now acclaimed as classics. Yet, Coltrane's music may be perceived as contradicting fractal, mathematical interpretations of Birkhoff's (1933) Theory of Aesthetic Value through exhibiting Brown noise rather than pink noise. He also developed novel techniques such as multiphonics (playing more than one note at the same time). His multi-tonic changes (rapid harmonic changes) created polypentatonic possibilities (improvisations in the pentatonic scales) in compositions such as "Giant Steps," (Yamaguchi and Sweet 2002) now considered a masterwork, but which was described by critics of the time, Ben Ratliff reports, as suffering from "rhythmic stiffness and melodic tameness" (Ratliff 2007). This analysis of "Giant Steps" did indicate that the rhythm was more predictable than much of his later work. During his second period, Coltrane was focused on developing a technical expertise and his performances were more predictable.

However, Coltrane's improvisations did not fit with the typical conventions and were not judged as aesthetically pleasing, but rather were harshly criticized as "anti-jazz" as early as 1961 (Nisenson 1995). Coltrane began emphasizing more rhythmic irregularity than the eighth-note rhythm characteristic of his second period, yet he fluctuated between eighth-note rhythmic patterns and rhythmic irregularity during

Table 8.1 The scaling exponent, α, for each piece

Time period	Year	Note count	Song	Album	Scaling exponent α	r
2nd	1959	777	**Giant Steps**	Giant Steps	1.76	0.96
2nd		556	**Some Other Blues**	Coltrane Jazz	1.77	0.95
3rd	1960	867	My Favorite Things	My Favorite Things	1.77	0.98
3rd		664	Equinox	Coltrane's Sound	1.67	0.96
3rd	1961	946	**Impressions**	Impressions	1.74	0.93
3rd		1,162	Spiritual	Live at the Village Vanguard	1.68	0.97
3rd	1962	532	Tunji	Coltrane	1.69	0.97
3rd		420	Nancy	Ballads	1.70	0.94
3rd	1963	238	Lush Life	John Coltrane, Johnny Hartman	1.75	0.98
3rd		396	Alabama	Live at Birdland	1.76	0.96
3rd	1964	995	Acknowledgement	A Love Supreme	1.72	0.96
3rd		602	**Crescent**	Crescent	1.64	0.95
3rd	1965	649	**Ascent**	Sun Ship	1.74	0.95
4th		306	Welcome	Kulu Se Mama	1.75	0.94
4th	1966	529	Naima	Live at the Village Vanguard Again!	1.71	0.93
4th		716	Crescent	Live in Japan	1.66	0.95
4th	1967	782	**Jupiter**	Interstellar Space	1.65	0.88
4th		621	Expression	Expression	1.65	0.94
	Mean	623.29			1.71	0.95
	SD	212.98			0.05	0.02

Since $f^{-\alpha} = 1/f^{\alpha}$, the scaling exponent is the absolute value of the spectral slope given by fitting a regression line on a double logarithmic plot of the power spectrum; r is the correlation coefficient between the frequency and power in logarithmic units. The pieces in bold have a series of regularly spaced peaks in their mutual information graphs in Figs. 8.1, 8.2, 8.3, 8.4, 8.5, 8.6

his third period, and this rhythmic irregularity became more characteristic during his fourth period. It is well known that Stravinsky's *Rite of Spring*, a challenging piece of music with strong dissonant qualities, caused a riot in its first performance. Performances in the later years of Coltrane's life were described as "angry" (Ratliff 2007, p. 131), "blaringly abrasive" (Niesenson 1995, p. 203), and "harsh, flat, querulous and at times, vindictive" (Fraim 1996, p. 64). A session at New York's Village Theater (later Bill Graham's Fillmore East) in December of 1966 caused a number

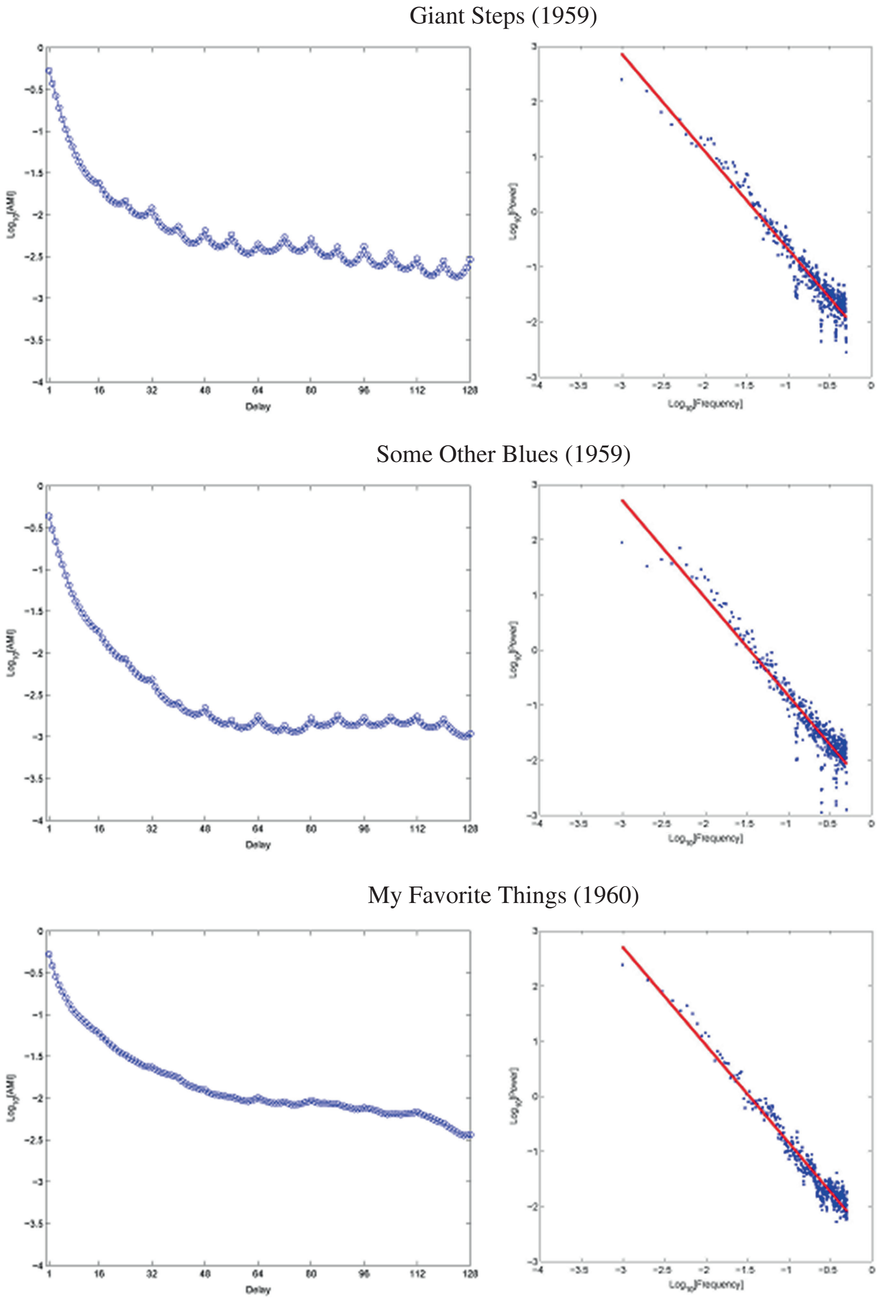

Fig. 8.1 Mutual information and spectral plot, respectively, for songs from 1959 to 1960

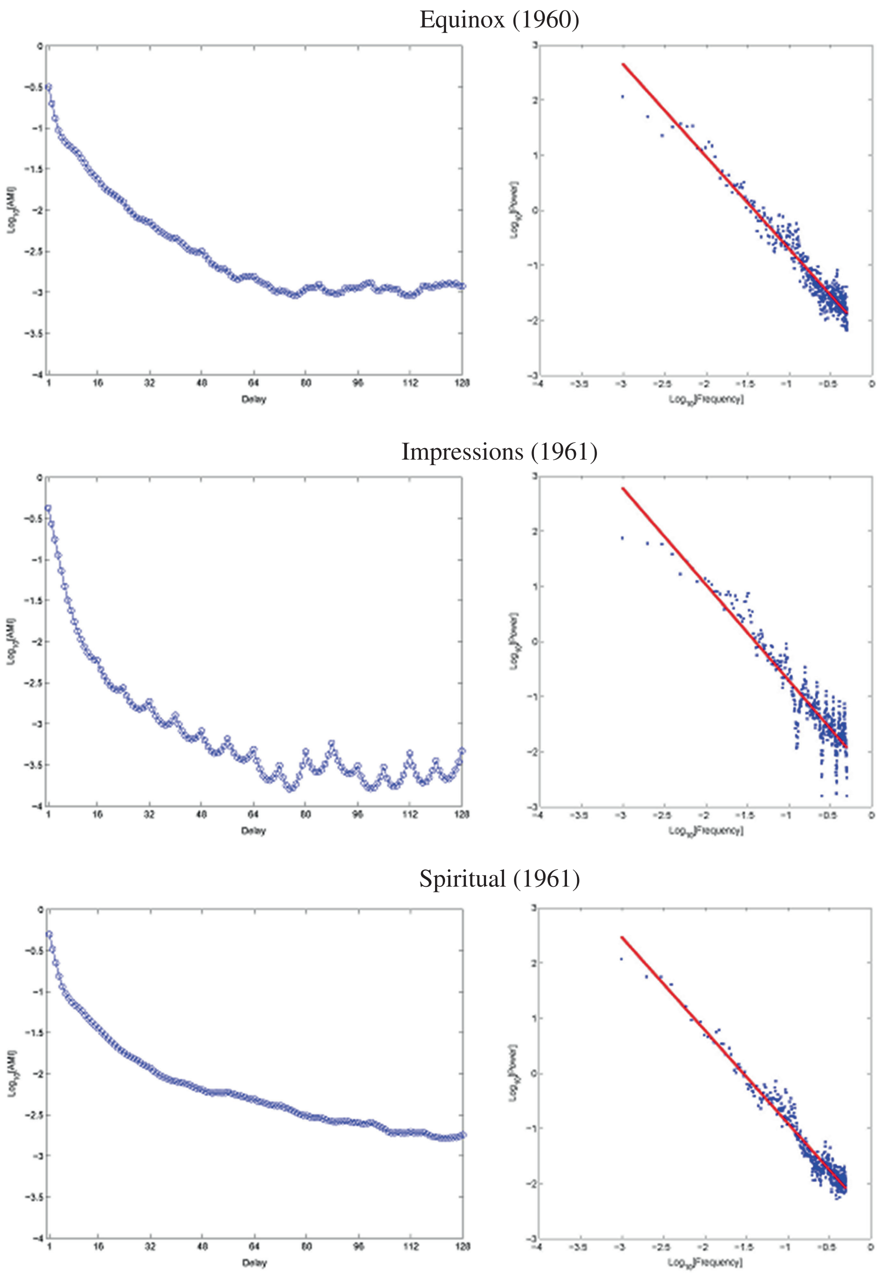

Fig. 8.2 Mutual information and spectral plot, respectively, for songs from 1960 to 1961

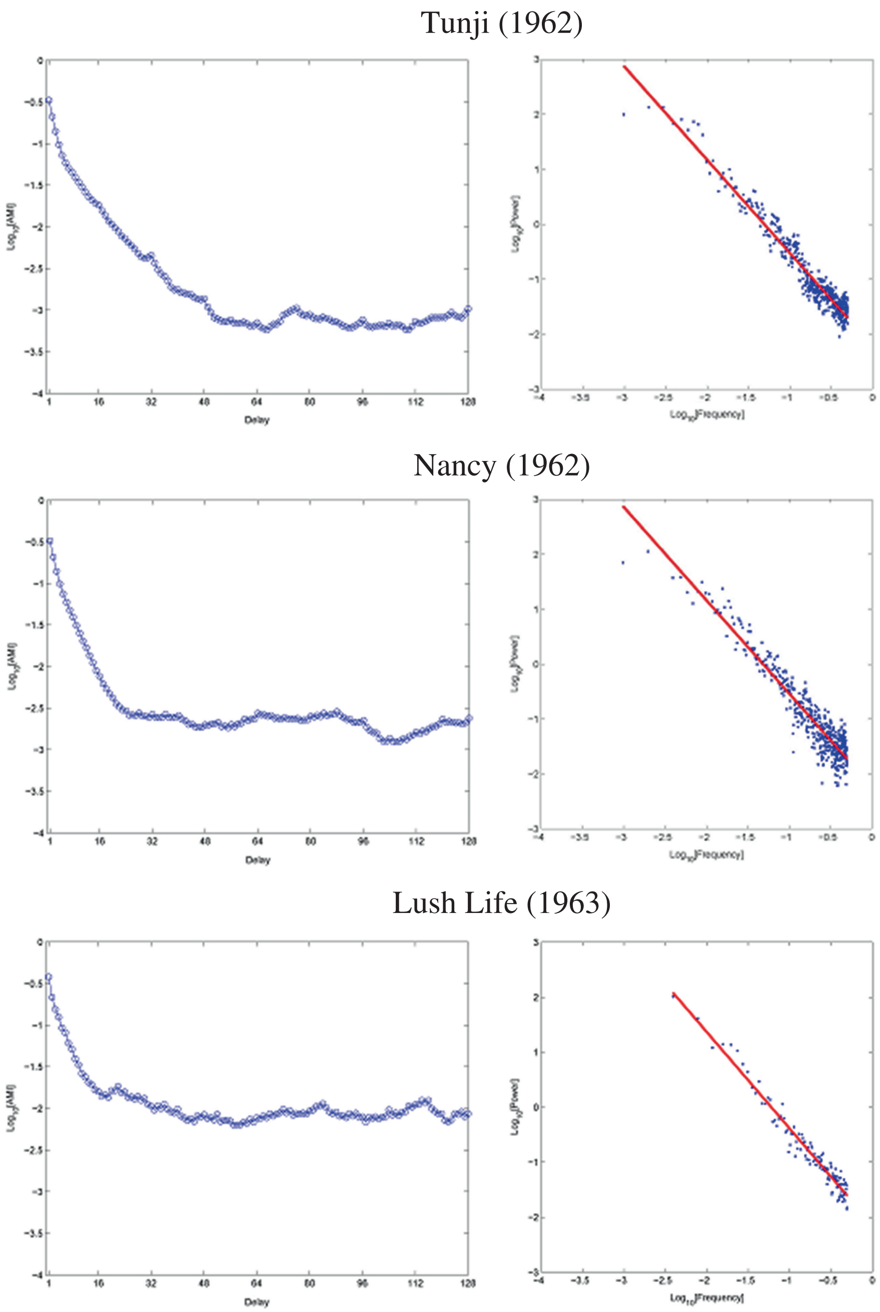

Fig. 8.3 Mutual information and spectral plot, respectively, for songs from 1962 to 1963

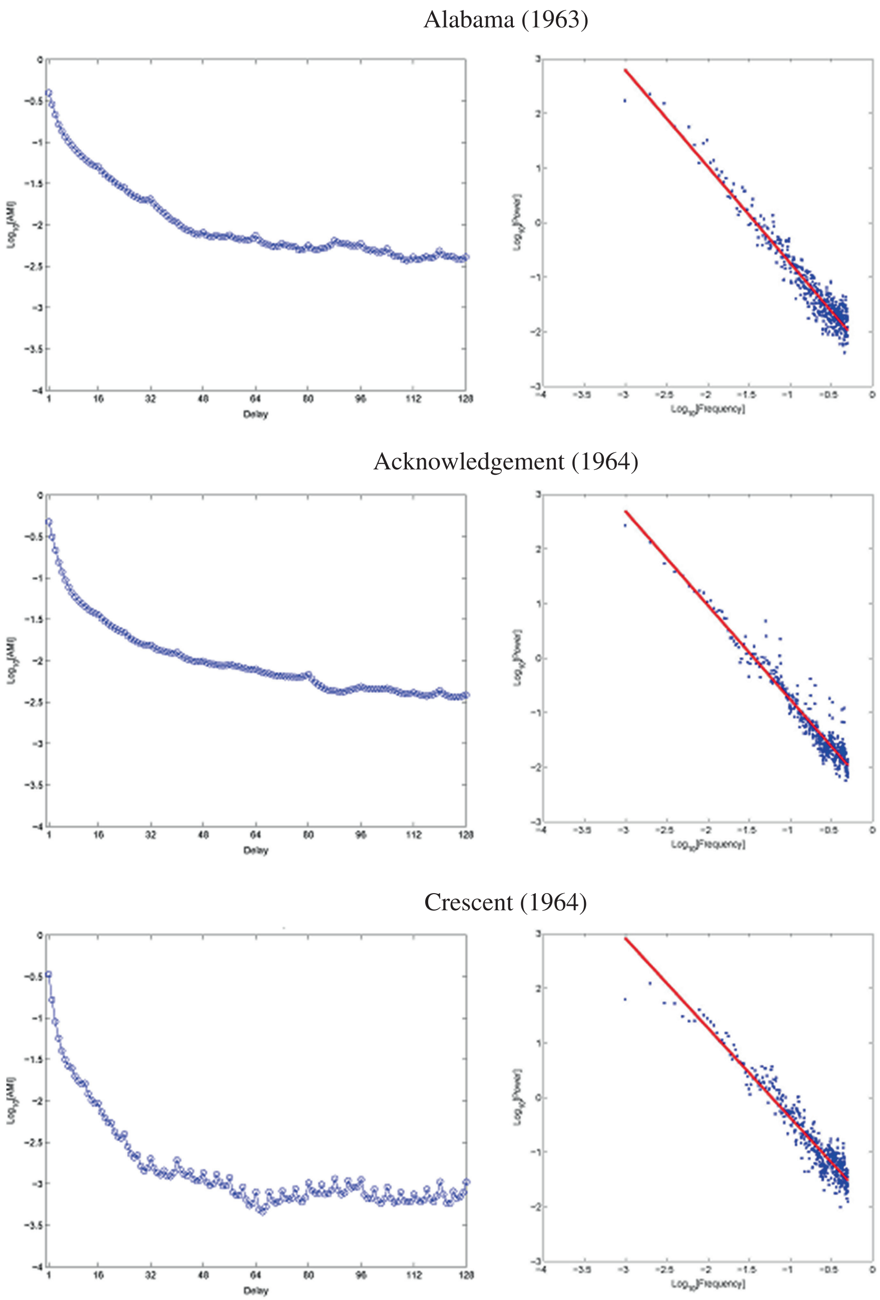

Fig. 8.4 Mutual information and spectral plot, respectively, for songs from 1963 to 1964

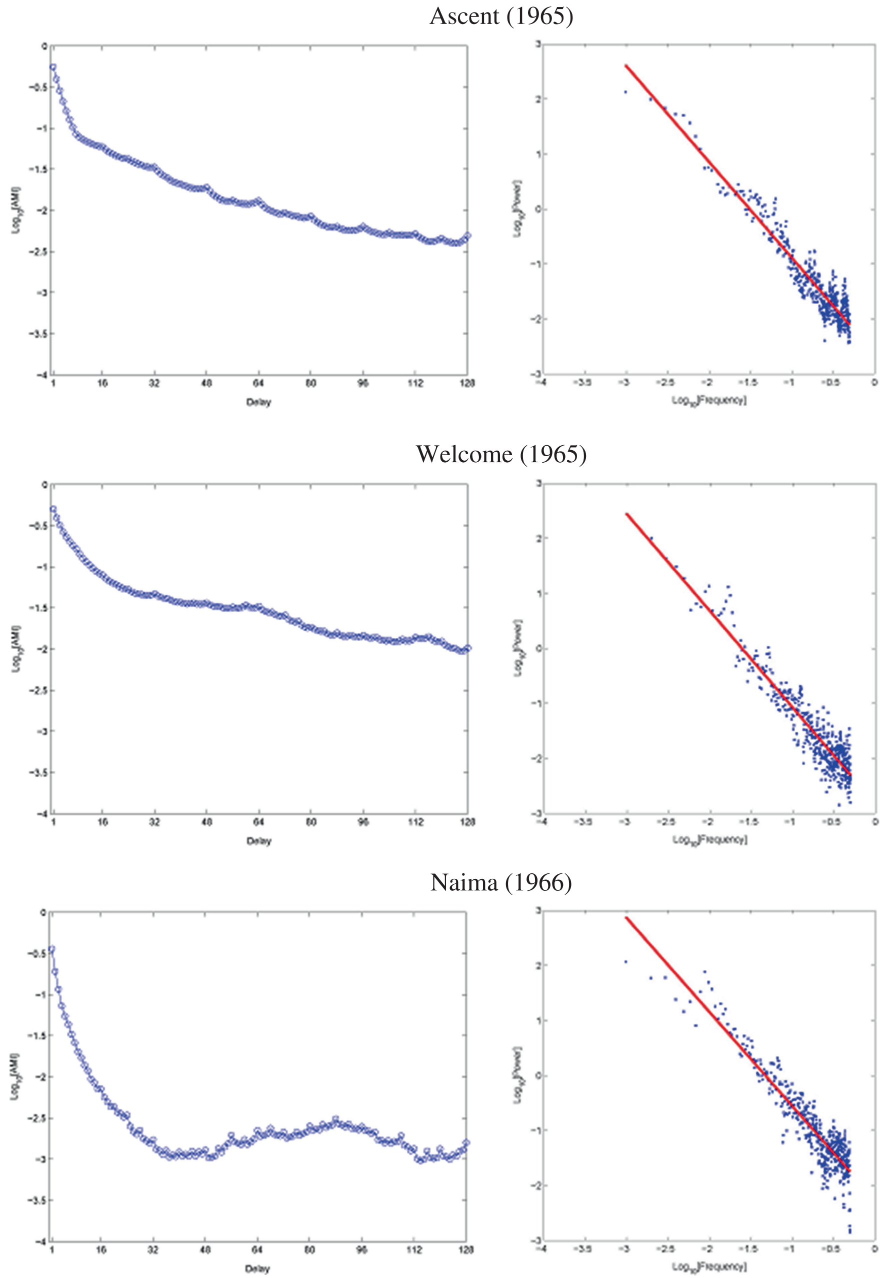

Fig. 8.5 Mutual information and spectral plot, respectively, for songs from 1965 to 1966

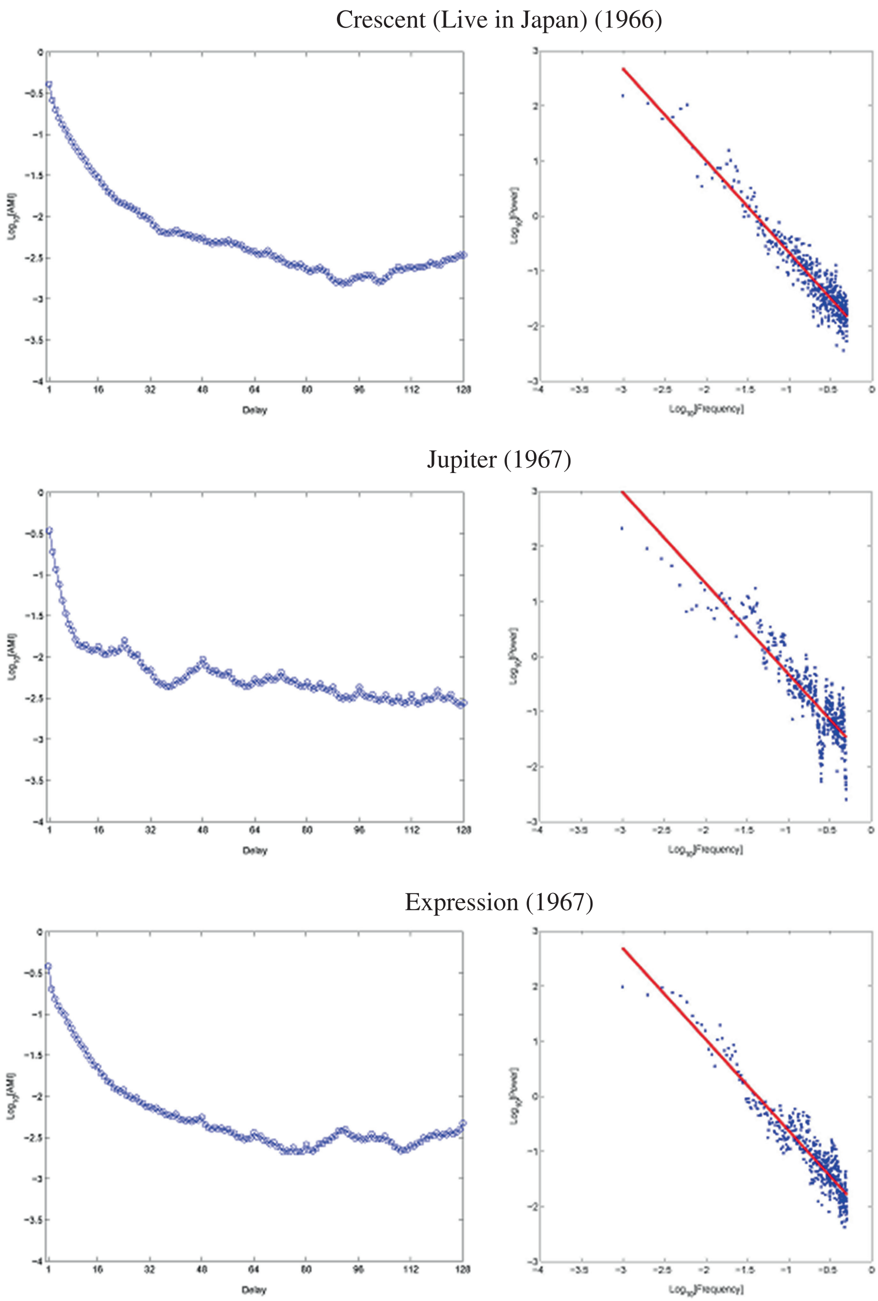

Fig. 8.6 Mutual information and spectral plot, respectively, for songs from 1966 to 1967

of persons in the audience to walk out, yet others were enthusiastically shouting (Fraim 1996). His later work (1964–1967), however, continues to be misunderstood and criticized today—even among jazz aficionados.

This fractal analysis supports the notion, advanced by Lewis Porter, that "What seems to be chaotic [in Coltrane's later work] is just the opposite" (Porter 1998). Coltrane's work during his fourth period still displays fractal qualities. The fractals of this later work are often even less predictable than his early work, yet are still robustly fractal. Before his death at age 40, Coltrane strove to have no boundaries or limitations to constrain his improvisations. Coltrane constantly challenged himself to expand upon his technique throughout his career even when he was already an accomplished musician.

8.8 Birkhoff's Theory of Aesthetic Value

A long-standing speculation is that $1/f^{\alpha}$ scaling in music arises as a consequence of the inherent aesthetics of music itself. Some patterns are thought to be intrinsically more pleasing to the human ear than others. Jeong et al. (1998), for example, suggested that most listeners prefer $1/f^{1}$ music to music with an uncorrelated white noise ($1/f^{0}$) structure or highly correlated Brown noise ($1/f^{2}$) structure. In fact, the form of $1/f^{1}$ scaling that comprises pink noise represents a compromise between complete randomness (white noise) and highly constrained Brownian patterns of variability. Essentially the Theory of Aesthetic Value, described by Birkhoff (1933), and similar hypotheses suggest that interesting pieces of art somehow strike balances between the expected and the unexpected, between repetition and contrast. Various ranges of the scaling exponent, α, have been interpreted as being consistent with Birkhoff's theory. Schroeder suggested that scaling exponents α between 0 and 2 fall into the Theory of Aesthetic Value, yet he suggested that the middle, α closer to 1, may be more aesthetically pleasing (Schroeder 1990). Voss and Clarke (1975, 1978) suggested that listeners aesthetically prefer pink noise ($0.5 < \alpha < 1.5$) over Brown and white noise. Both Schroeder and Voss and Clarke may have interpreted Birkhoff differently regarding the Theory of Aesthetic Value. Based on this analysis of Coltrane's solo improvisations, the numerical range for the Theory of Aesthetic Value also include anti-persistent fractional Brownian motion. Coltrane's earlier improvisations were even more Brownian than his later improvisations, which were closer to the pink range already interpreted as the Theory of Aesthetic Value by Voss and Clarke. However, it is also important to note that the music that they analyzed lasted for hours and had more variability (and noise) than the solos from one single musician.

There is merit to Birkhoff's Theory of Aesthetic Value perspective and to Schroeder's suggestion that this theory may be quantified in terms of spectral slopes or scaling exponents. However, none of Coltrane's solos display pink noise. Instead, they are best characterized as fractional Brownian Motion (Eke et al. 2010), which was also found to characterize classical and jazz music (e.g., Boon and Delcroly 1995), but using different pitch encoding than in the present study. Yet Coltrane's solos still display order and complexity that is aesthetically pleasing. Although the comparison of audience reactions to music is complicated by the evolution of cultural aesthetics over time, some of Coltrane's pieces have been called dissonant or avant-garde sounding to the novice listener, while others, such as "Giant Steps," are quite pleasing to the listener, even though earlier on some critics did not accept this music. Yet both display a Brownian trajectory in their pitch sequences. Within these spectra, "Giant Steps" has greater predictability and to the novice listener is more pleasing to the ear. In contrast, the later work of "Jupiter" and "Crescent" (*Live in Japan*) demonstrates less predictability and may sound like there is less order to the average ear. The average ear may be frustrated since the motion in the piece is less predictable. However, these pieces display Brownian motion, which involves both order and unpredictability between successive notes.

What can be learned from the qualitative patterns that unfold in John Coltrane's, or any individual's, life experience? Proposing easily testable hypotheses in this realm is difficult. Nevertheless, suppose one transfers the metaphorical concept of metastable dynamics to the qualitative realm of an individual's life experience. It is possible to frame creativity, intelligence, and especially development in a manner that is qualitatively consistent.

Robert Sternberg observed in 2001 that many descriptions of intelligence share an emphasis on adaptation, the ability to effectively mesh with one's surrounding environment (Sternberg 2001). He described wisdom as balancing the forces of change implied by creativity with the stability or inertia of an existing adaptive state implied by intelligence. For Sternberg, the continuous interplay of intelligence, creativity, and wisdom form a dialectic spiral. Clearly, Sternberg's hypothesis emphasized interactive relationships. More broadly, contemporary developmental scientists describe the outcomes of development as a probabilistic bidirectional interplay between the constraints supplied by genetic and neural activity, behavior, and the physical, social, and cultural environment (Gottlieb 1998).

Previous analyses that found pink noise in musical performances focused primarily on the patterns of oscillation in the relative volume (loudness) of the pieces and did not assess the patterns of the played notes. This outcome leads us to speculate that aesthetic value may reside in the quantitative patterns that emerge in artistic performances. However, aesthetic value is often judged in the context of the milieu of human and artistic culture, and analyses such as those in the present study may influence judgment and acceptance of creative works.

In conclusion, Coltrane's improvised solos are comprised of fractal patterns that appear to contradict those predicted by the pink noise identified in classical, jazz, and blues music compositions (Hsu and Hsu 1991; Hughes et al. 1998; Voss and Clarke 1975, 1978). Instead, this findings confirm that Coltrane's work, including his later avant-garde improvisations, display the same numeric complexity and order (Birkhoff 1933) with spectral slopes close to -2, or more specifically scaling exponents α in the average range between $1.6 < \alpha < 1.8$. Although Jean Pierre Boon and Olivier Delcroly (1995) analyzed performances by a musician using a synthesizer connected to a computer to encode pitch, which is different from the present study, they also found that the spectral slopes for pieces by Wolfgang Amadeus Mozart, Johann Sebastian Bach, Thelonious Monk, Bill Evans, and other classical and jazz music were even closer to −2, (approximate range of the scaling exponents α in between $1.8 < \alpha < 2.2$).

In comparison with his earlier work, Coltrane's later fourth period illustrates greater complexity, unpredictability, and aesthetic value that may be misunderstood by the average listener. In essence, Coltrane continually developed his self-expressions on the saxophone that are evident from his early work during his second period and especially through his later work during his fourth stylistic period. Through exploring the spatiotemporal properties and stochasticity of Coltrane's music, there is evidence of eminent creativity (Schuster 1983). Some researchers suggest that specific conditions such as flow (creating in the moment), intrinsic motivation, tolerance for ambiguity, and risk taking lead to high levels of creativity within individuals (Csikszentmihalyi 1990). John Coltrane was able to take his music to another spatiotemporal level. As a result, Coltrane was able to withstand the constraints of time by sounding absolutely current in any era for multiple generations of listeners. Perhaps this is the reason why Coltrane will continue to be considered one of the most innovative musicians in jazz and music generally.

In order to better understand the complexity between improvisation and creativity, fractal analysis offers promise to address their dynamics and intricacy with greater depth. Fractal analysis can address dimensionality that standard approaches may overlook. Furthermore, the mathematical properties are unbiased and can address the dynamics of culture with greater perfection and accuracy. Brownian motion may also be more aesthetically pleasing than previously suggested. Brown and Albert Einstein discuss its beauty and value, not only aesthetically, but also empirically through the scientific method. Fractal analysis, as developed Fourier, offers a useful method for understanding the complexities of music improvisation.

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Chapter 9
Art, Creativity, and Culture: How Art Intersects with Science in the Expression of Artistic Creativity

Christine Charyton

Abstract Almost a half century ago, Snow (The two cultures and the scientific revolution. Cambridge University Press, New York, 1959) identified a problem that still needs discussion. Snow felt that he was living in two distinct separate cultures that ceased to communicate among each other. The two cultures would use distinct terminology and have a lack of understanding of each other. Snow felt that although these cultures were discrete, yet he felt commonalities between the two. One commonality was that he was a part of both cultures. Previous studies (Charyton in Creativity (Scientific, artistic, general) and risk tolerance among engineering and music students, Temple University, 2005, Charyton in Creativity (scientific, artistic, and general) and risk tolerance among engineering and music students. VDM Verlag Publishing, Germany, 2008; Charyton and Snelbecker in Creativity Res 19:213–225, 2007a, Charyton and Snelbecker in Psychol Aesthetics Creativity Arts 1:91–99, 2007b) addressed specific domains of creativity in both science and art as well as the intersection of both science and art. Discussion about personality characteristics of scientists and artists are discussed along with case studies. Case studies are discussed for the cultural intersections of the East (Asia) and West (Europe) with science and art. The Ukrainian culture is also discussed as a culture unifying the East and the West as a bridge where eminent Ukrainian persons may more often excel in more than one discipline as polymaths. Recent political concerns in Ukraine are described in relation to creativity, innovation, and culture as well as exceptionality in both the sciences and the arts as polymaths as an occurring aspect of the Ukrainian culture.

Keywords Art · Science · Polymath · Ukraine · Culture · Creativity · Innovation · Personal attributes · Scientists · Artists

C. Charyton (✉)
Ohio State University Wexner Medical Center, Columbus, OH 43210, USA
e-mail: charyton.1@osu.edu; Christine.Charyton@osumc.edu

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9.1 The Two Cultures

Almost a half century ago, Snow (1959) proposed a problem that still needs to be addressed today. By training, he was a scientist and by vocation, a writer. Snow felt that he was living in two distinct separate groups that were comparable in intelligence and social origin, yet they ceased to communicate with each other. Snow described the two cultures as the culture of scientists and the culture of artists. The two cultures would use distinct terminology and have a lack of understanding of each other. However, both have commonalities. One commonality was that, as an individual, he was a part of both cultures.

Previous studies (Charyton 2005, 2008; Charyton and Snelbecker 2007a, b) addressed specific domains of creativity in both science (engineering) and art (music). This area of interest is expanded upon to investigate how some artists are also scientists, or how individuals can exceptionally excel in more than one domain. Creativity occurs when a person makes a change in a domain that will be transmitted through time (Csikszentmihalyi 1998). There is a thematic continuum between art and science foci on inner (feeling and emotion: art) and outer (things: science) worlds (Stent 2001).

Past American Psychological Association (APA) President, Robert J. Sternberg, stated through an unsolicited listserv e-mail correspondence "…this is a great topic! The relationship between scientific and artistic creativity has been addressed as a meaningful topic for discussion. The two types of creativity have always seemed to me different, but similar, in that much of scientific creativity has an aesthetic side to it" (R.J. Sternberg, personal communication, May 18, 2001). According to Simonton (1999), "Researchers often treat creativity as a single, relatively homogeneous phenomenon" (p. 639). Simonton also found this topic interesting and suggested I contact Gregory Feist who expressed interest and support. "Few topics are of greater importance to psychology than creativity" (Feist 1999, p. 289). Individuals who possess scientific and artistic creativity are driven to create and solve problems originally and adaptively, which is by definition creativity. "We have only begun to establish covariation between personality and creativity" [in artistic and scientific creativity] (Feist 1999, p. 289). Personality attributes and environmental factors will be explored in regard to case studies regarding how science and art can be intertwined.

9.1.1 Creative Personal Attributes

Personal characteristics vary according to the type of creative achievement (Feist 1999; Simonton 1999). For example, creative scientists exhibit traits somewhere between those of the creative artist and those of the noncreative convergent scientist. There appear to be only small domain-specific variations in creative attributes (Charyton 2005, 2008; Charyton and Snelbecker 2007a, b; Guastello 2009).

Universal factors include that creativity requires discipline, persistence, and hard work (Ivcevic and Mayer 2007) as well as openness to experience are important regardless of domain (Dollinger et al. 2004; Feist 2010, 2013).

A primary difference between scientific and artistic creative personality is that art is an introspective journey, while science is more externally focused (Feist 1999). Furthermore, divergent thinking may be limited to the domain of the scientific environment in science (Simonton 1999). One is creative within their own specific domain (Gardner 1999). However, creative traits cut across disciplines such as intrinsic motivation, wide interests, open to experience, and autonomy (Barron 1995; Charyton et al. 2009; Helson et al. 1995; Kozbelt et al. 2010).

Feist (1998, 1999) and Feist and Barron (2003) among others investigated the influence of personality on artistic and scientific creativity. Feist (1998) conducted a meta-analysis of personality attributes of scientists and artists to shed light on these domains. The five-factor model (FFM) or the "Big Five" include the following: extraversion (E), agreeableness (A), conscientiousness (C), neuroticism (N), and openness (O). The definition of creativity generally failed to account for other important observable aspects of creativity such as the person and product (Feist 1999). The following are measurable personality attributes of artists and scientists that distinguish similarities and differences between artistic and scientific creativity.

9.1.2 Artists

Artists were defined as persons earning an income in writing, painting, photography, cinematography, dance, music, or poetry (Feist 1998). Artists compared to nonartists were less cautious, conscientious, controlled, orderly, and reliable as well as less conventional, rigid, and socialized. The artists were more aesthetic, creative, curious, imaginative, open to experiences, sensitive, and original. Feist (1999) also explored nonsocial traits of artists to include openness to experience, fantasy, and imagination. Nonsocial negative traits include impulsivity and lack of conscientiousness as well as anxiety, affective illness, and emotional sensitivity. Furthermore, open people may have developed cognitive skills associated with divergent thinking, flexibility, and fluidity of thought.

Personal creative characteristics that stand out in artists include strange and eccentric, asocial, independent, and nonconforming (Getzels and Csikszentmihalyi 1976). Art students were significantly different from the norm in that they are socially withdrawn, introspective, independent, imaginative, unpredictable, and alienated. Artists rather than scientists tended to be much lower than the norm on socialization, commonality, tolerance, and responsibility (Feist 1999). Social traits for the artist included norm doubting, nonconformity, independence, hostility, aloofness, unfriendliness, and lack of warmth.

Artists were identified as emotionally less stable, cold, and rejecting group norms than scientists (Feist and Barron 2003). A stereotype that some researchers support is that the artist is emotionally liable, manic, expressive, and a sensitive person (Feist 1998). “Artists are supposed to be moody, extravagant, unreliable, promiscuous and altogether a bad match for one’s daughter” (Getzels and Csikszentmihalyi 1976, p. 34). Artists rated higher on psychoticism and neuroticism on the Eysenck Personality Questionnaire than nonartists (Booker et al. 2001). Artists may be emotional sensitive, independent, impulsive, and aloof in addition to nonconforming (Barron 1972).

A few studies, however, reported high levels of extraversion among creative performing artists such as opera singers (Hammond and Edelmann 1991). According to Runco and Bahleda (1986), characteristics of artistic creativity include expressive, imaginative, humorous, open-minded, unique, emotional, and exciting, while scientific creativity characteristics include perfectionistic, intelligent, curious, patient, and thorough. Artists prefer inventing and developing new ideas of their own and prefer change to status quo (Gridley 2006). Most assume that all artists are creative, while that is not the assumption of all scientists. Creativity needs to be expressed in both science and art, both equally important.

9.1.3 Scientists

Feist (1998) defined science was not only limited to natural or biological but also included social sciences, invention, mathematics, and engineering. Scientists were almost half a standard deviation higher than nonscientists on traits of aggressive, cold, egocentric, impersonal, impulsive, antisocial unempathetic, creative, and tough minded (Feist 1998). Creative scientists versus nonscientists were more aesthetically orientated, ambitious, confident, deviant, dominant, expressive, flexible, intelligent, and open to new experiences when compared to their noncreative counterparts. High creativity often takes place in science by major revolutions or changes in science (Sulloway 2009). Furthermore, scientific productivity as an indicator of scientific achievement is often measured through scholarly publications in science (Charyton et al. 2014, 2015; Grosul and Feist 2014). Charyton et al. (2008) found that college students tended to list scientists more often as creative than artists, contrary to popular stereotyping opinion that may suggest that artists are first to be considered as creative.

Scientific creative persons in natural science, biology, social science, engineering, and math exhibited nonsocial traits of openness to experience and flexibility in thought (Feist 1999). These creative scientists also exhibited remarkable drive, ambition, and high achievement levels. According to Amabile (1994), productive researchers tended to be ambitious, unsociable, nonanxious, defensive, and approval seeking, while creativity ratings of scientists correlate negatively with sociability, good impression, and empathetic. Women scientists tended to be more serious, radical, confident, dominant, intelligent, and adventurous in comparison with other women, while less sociable, group dependent, and sensitive. Many psychological studies of scientific creativity explored the deviation of scientists. Social traits of scientific creative personality include dominance, arrogance, hostility, and high self-confidence. In some research on young scientists, self-confidence appeared to be the primary indicator of success in science (Sansanwal and Sharma 1993). The scientific elite also tended to be more aloof, asocial, and introverted than their less creative peers (Feist 1999). Scientists are less actively nonconforming than artists and scientists tend to be more conscientious and orderly than nonscientists (Wilson and Jackson 1994). Furthermore, scientists are likely to use imaging, abstracting, and recognizing patterns in scientific thinking (Root-Bernstein 2003).

9.1.4 Commonalities

Both creative scientists and artists were more aesthetic, creative, and open to experiences (Feist 1999). Creative people tended to be more autonomous, introverted, self-confident, hostile, and impulsive (Feist 1998, 2010, 2013). Artists and scientists tended to differ on emotional sensitivity; however, low socialization and nonconformity are common traits of both artistic and scientific creative personality (Feist 1999, 2010, 2013) (see Table 9.1). Additional commonalities between scientists and artists included hostility and arrogance. Also, in order to achieve and move forward against the status quo, high energy, drive, ambition, and flexibility of thought were common. Independence, introversion, openness, hostility, and dominance may exist early in the artist's and scientist's personality.

Farley (1991) suggested that creative individuals, or persons with higher Type-T or risk taking behavior, prefer uncertainty, unpredictability, high risk, novelty, much variety, complexity, ambiguity, low structure, high intensity, and high conflict. Charyton and Snelbecker (2007b) explored the top 10 adjectives were analyzed in both number and specific descriptive selections for each group, gender, and major in engineering and music students (see Table 9.2).

All four groups selected common descriptors but tended not to consider *commonplace*, *conventional*, *interests-narrow*, and *submissive*. Engineers selected *individualistic* and *resourceful*, whereas musicians selected *interests-wide* and *insightful*. The most unique adjective was one adjective per each major-gender group. Overall engineering and music students shared more traits in common than anticipated.

Table 1 Positive and negative personality attributes shared among creative scientists and creative artists based on Feist (1999, 2010, 2013)

Negative attributes shared (pro-creativity)	Positive attributes shared (pro-creativity)
Decreased socialization	Nonconformity
Hostile	Autonomy
Impulsive	Self-confident
Arrogant	Introverted
Dominance	Open to experience

Table 2 Common adjective selections compared to unique adjective selections for male and female engineering students and musicians based on Charyton and Snelbecker (2007b)

Discrete, unique descriptors	Common descriptors
Engineering males—cautious	Capable
Engineering females—confidence	Humorous
Male musicians—originality	Intelligent
Female musicians—reflective	Honest
Males—clever, females—mannerly	Sincere

Other personality psychologists state that five bipolar dimensions to personality include openness, neuroticism, extraversion, agreeableness, and conscientiousness (Feist 1999). Noncreative characteristics included boring and narrow interests. It is interesting to note that common perceptions of everyday and artistic creativity have more commonalities than everyday and scientific creativity, or scientific creativity with artistic creativity. Most people perceive creativity to be artistic at first glance.

9.2 Art and Science as Interrelated Entities

Art and science are sometimes intertwined in the same individual. Scientists also can have interests and hobbies in the arts. For example, in addition to sharing interests in physics, Max Plank and Albert Einstein used to play music together, piano and violin, respectively. Zichichi (1999) described the meaning of creativity from a combined art and science prospective. Language, logic, and science can lead toward creation. Zichichi defined language as literature, music, arts, theater, economy, politics, and other manifestations. Furthermore, he stated that these areas could exist even if logic or science had never been discovered. Yet it is implied that scientific creativity needs language (music, art, literature, theater, economy, and politics).

Charyton (2005, 2008) and Charyton and Snelbecker (2007a) investigated similarities and differences in general, artistic, and scientific creativity between engineering versus music students, as two groups, respectively, representing scientific and artistic domains. One hundred music and 105 engineering students from a large, Northeastern university completed measures of general creativity, music creativity, engineering creativity, and a demographic questionnaire. Results indicated that musicians scored higher in general and artistic creativity, with no significant differences in scientific creativity. Participants had higher levels of creativity, compared with normative data from previous studies. Gender, age, and specialization within major yielded no significant differences. Implications addressed general and domain-specific creativity. Furthermore, Charyton and Snelbecker (2007b) also concluded that engineering students and music students shared more in common than had differences.

Art and science are somewhat interrelated with each other as well as with culture. Yaroshevskii (1987) stated that artistic style and scientific paradigm are equally determined by cultural factors. This product reproduces the particular individual's intellectual involvement in the transformation of ideas, which is an activity of creativity. Runco (1993) expressed the dialogical need for art and science to enhance each other in the creative process. For example, a "potential photographer's interests and skills must be synchronized with technology, as well as with a cultural appreciation for this kind of art" (p. 104). Furthermore, creativity needs to be understood from an interdisciplinary perspective (Yaroshevskii 1987). In the study of genius, polymathy is more common (Root-Bernstein and Root-Bernstein 2004). Polymaths excel in multiple areas and make transdisciplinary discoveries (Root-Bernstein 2003). For example, Robert Brown was a botanist and an artist as well as an explorer (Charyton et al. 2012; Charyton 2014a). Furthermore, in both art and science, works are influenced by nature (Root-Bernstein and Root-Bernstein 2004).

Weisberg (1999) stated that the relationship between creativity and knowledge may be even more straightforward than theories typically assume. One may be creative after some sort of knowledge is acquired in that specific domain. The fact that one individual creates more in a specific domain area could be explained by the individual's specific knowledge. Hence, creative thinking as a process could be based more on the direct application of knowledge.

According to Feist (1998), in order for a product to be considered creative, the thought or behavior must also be socially useful or adaptive. Creativity requires both novelty (originality) and usefulness (adaptiveness). Artists and scientists have frequently been the populations for studying such phenomenon. Science and art are equally creative (Feist 1998). The differences in art, science, and everyday life are important subjects to study when considering psychological processes. Similarly, creativity and innovation are intertwined yet distinct entities (Simonton 2013).

The environment can play a key role in creativity and innovation. According to Czikszentmihalyi (1988), the environment where creativity is exercised may be more important than the definition of creativity. Creativity is rarely from the isolated individual, but rather it is the product of three shaping forces. These forces are a set of social institutions or the *field*, a cultural *domain* that is determined by generations and the *individual* that may change the field in which he or she is creative. Thus, the sciences or the arts may provide a cultural domain for the specific field in which the individual contributes. The combination of these three forces is vital for understanding creativity and innovation. Furthermore, art and science may be expressed within a cultural context.

9.3 Problem-Solving Case Studies in Both Art and Science

Weisberg (1995) stated that the basis for creativity is problem-solving and describes such findings through case studies which describe the rationale behind both artistic and scientific creativity. Problem-solving may have appeared more prevalent in science than art; however, *Guernica* proves the point that Picasso was making a personal statement regarding the Spanish revolutionary war. *Guernica* has great symbolic and political importance and is one of Picasso's most well-known and respected works, despite the considerable controversy it created at the time. Civil disturbances lead toward justice and less oppression (Martindale 1997).

Weisberg (1995) also stated that the double helix (DNA) was not a miraculous discovery but rather a problem-solving process by a group of individuals competing with each other to come up with the proper solution to this problem. "These cases show that there have been a number of significant creative accomplishments that have occurred on the basis of reproductive thought, that is, without restructuring" (Weisberg 1995, p. 61). Thus, their problem-solving was not completely novel. Rather, these creative individuals discovered the answer based on existing possible solutions of others. Furthermore, Weisberg (1986) stated after discussing the DNA and Darwin cases, "scientific creativity came about through the same sort of thought processes ordinary people use to solve ordinary problems" (p. 105). Likewise, Weisberg (1986) provided evidence that *Guernica* is essentially Picasso problem-solving and emulating from previous similar artwork, *Minotauromachy*, as well as other artist's artwork such as *The Massacre of the Innocents*.

Einstein stated that "the formation of a problem is often more essential than its solution, which may merely be a matter of mathematical skill or experimental skill" (Simonton 2003, p. 176), which supported the need to investigate individual differences such as creativity in science and art due to being overlooked and trivialized (Simonton 2003). Empirical research demonstrated that highly creative individuals differ from less creative individuals on cognitive and dispositional variables. Persons who displayed exceptional cognitive flexibility, openness to novelty, liking for complexity, tolerance for ambiguity, and defocused attention hold an advantage for cognitive breakthroughs (Simonton 2003).

9.4 Cultural and Environmental Factors: Art in the East and West

Art is often explored in Jungian analysis with a basis in Eastern philosophy. "Very often dreams occur which urge one toward creative expression" (Kreinheider 1973, p. 69). "Conformity and atrophy of the imagination are among the afflictions of our society" (Kreinheider 1973, p. 73). "The creative adventurer feels the pull of the undiscovered" (Kreinheider 1973, p. 76). Creativity is associated with *the way*, or the Chinese *Tao*, which leads toward individuation. Chung-Yuan (1963) stated that "The Tao" is the primordial source of creativity. In Chinese, peace means harmony and tranquility; tranquility is reflected in Chinese poetry and painting. The "true artist" and poet aim to bring forth the rhythm of the work and carry it beyond the beholder. Chinese mandalas play a role in Jungian art therapy and self-exploration through art (Kreinheider 1973). Art products, such as symbols, are composed of conscious and unconscious components. The awakening of creative intuition is applied to both poetry and painting (Chung-Yuan 1963).

According to Kuo (1996), Taoism played a role in the creative personality. Kuo stated that the teachings of Lao Tzu state that a sage be open-minded and discourages the use of will power. According to this Chinese philosophy, characteristics such as passivity, meekness, and sympathy give birth to the creative process. Just as science and art are opposites, the ying and yang are opposites that are not antagonistic, but complementary.

Niu and Sternberg (2001) compared East and West with the artwork of Chinese and American artists in regard to culture, style, and creativity and enhance our understanding about the effect of environmental factors on diversity (Niu and Sternberg 2001). Culture may have influenced the development of creativity through the influence of societal values. Findings were that American students showed higher artistic creativity in comparison with Chinese students by both sets of judges. Chinese judges tended to give higher ratings overall; additionally, American students received higher ratings on both creativity and aesthetic qualities and displayed more spontaneity and diversity in expressing their artistic creativity. Cultural and environmental factors are important to recognize and understand (Csikszentmihalyi 1988; Niu and Sternberg 2001; Simonton 1999). Furthermore, the cultural environment sets standards for creative products that individuals can internalize as part of their cognitive processes (Sternberg and Lubart 1996).

9.5 Case Study Bridging Art, Science, and Their Unification in Both East and West: Ukraine

Ukraine has often acted as a bridge from East (Asia) to West (Europe) and is viewed by many Ukrainians as a European nation. Furthermore, there has been a strong movement continually fighting Soviet and Russian oppression within Ukraine to embrace democracy (pro-creativity and pro-Western views) compared to communism or collectivism (countercreativity similar to Russia and China). Past perspectives of genius have overlooked social, political, and interpersonal creativity (Kinney 2000). This section will address social, political, and interpersonal factors in science and art for polymaths in the Ukrainian culture. The background of Ukraine with case studies of polymaths is provided to illustrate how lesser known Ukrainians have similarities to Leonardo Da Vinci and Benjamin Franklin, like the Renaissance as a part of the culture, especially of Ukrainians and Ukrainian Americans. These features could also be developed in other cultures. Religion, politics, science, and art are also discussed in relation to having a huge impact on Ukrainian culture and Ukrainian creative work by the people and for the people.

Many peoples have lived or passed through Ukraine such as Trypillians (5000 BC), Greeks (1000 BC), Cimmerians (1000 BC), Scythians (700 BC), Samaritans

(200 BC), Romans (200 AD), Huns (200 AD), Germans (200 AD), Celts (200 AD), Mongols (1200 AD), Tatars (1200 AD), Lithuanians (1500 AD), Poles (980 AD, 1300 AD, 1500 AD, 1800 AD, 1900 AD), Jews (900 AD), Turks (400 BC, 1200 AD), Russians (700 AD, 1100 AD, 1600 AD, 1800 AD, 1900 AD, 2000 AD), (Hrushevsky 1941; Subtelny 1988). Ukraine started as various Ukrainian regions with specific customs specific to each region from their own forefathers that fortified around the time of Volodymyr Velyky (Hrushevsky 1941). Kyiv Rus began around 700 AD with the rise of Kyiv that had Greek trade routes (Subtelny 1988). Kyiv prospered with Volodymyr Velyky (980–1015 AD) (Hrushevsky 1941). Regions of western Ukraine were called Galicia beginning from 1189–1205 which had several invasions from Poles and Tatars to Genghis Khan (Hrushevsky 1941). In 1648, Bohdan Khmelnytsky was instrumental in a great uprising fighting the Poles (Subtelny 1988). At this time, both Poles and Russians had the intent of monopolizing power. Hryhorii Hranianka contributed to arts and culture with his literary work "The Most Bitter Wars of Bohdan Khmelnytsky" to show that "Ukrainians are the equal of others" (Subtelny 1988, p. 197).

In 2013, the population was 48 million people were in Ukraine, while 30 million identify as Ukrainian with 15 million Ukrainians outside Ukraine in other countries (Ponomarenko 2013). In 2014, the population of 45.42 million people live in Ukraine (39 % Kyivian Orthodox, 29 % Moscovian Orthodox, 14 % Ukrainian Catholic (Byzantine), 3 % Autocephalous Orthodox, 2 % Protestants, 0.6 % Muslim, 0.2 % Jewish, and 0.1 % Buddhist) (Janssen 2014).

National emblems have been selected by history to various political, social, and cultural factors (Kubijovyc 1963). Some people view Ukraine as in the East or at least Eastern Europe. In many ways, this region of Europe unifies the East and West as a bridge or "*mict*" (*pronounced meest*), with its European traditions. "Ukraina" translates to border-land in the twelfth century and in the nineteenth century meant Kozak (Cossack) state to protect Christianity and the boundary between Asiatic East and Western Europe (Ukrainian Orthodox Church 1988). The Ukrainian emblem, similar to the USA eagle, has been the Tryzub or trident since 950 AD at the time and influence of Volodymyr Velyky and was imprinted on currency coins. Tryzub literally translates to "three tooth"—"try (tre)" meaning "three" and "zub" meaning "tooth." This symbolized the battle of the forces of evil to symbolize a struggle for goodness and truth (*Pravda*). These coats of arm were initiated by Volodymyr Velyky (Volodymyr the Great) who was the political leader (was Prince and King of Ukraine and later a Saint) that chose Christianity over the Muslim religion since he did not want to forbid alcohol consumption for himself as well as the Ukrainian people. Saint Volodymyr (978–1015) built a Christian empire where Ukrainians were baptized (Hrushevsky 1941). Other Saints were also instrumental in bringing Christianity to Ukraine such as Apostle Saint Andrew (Andriy) and Saint Olha. Ihor's widow Olha (945–960) was well respected because she adopted Christianity. Both Saint Volodymyr and Saint Olha had a large impact on Ukrainian culture through the adoption of Christianity.

9.5.1 Trypillians: Ancient Ukrainians

Art, poetry, music, singing, and dancing are an integral part of the culture of Ukrainians and Ukrainian Americans. A region of Ukraine was the birthplace of Trypillians around 5000 BC which was also rich in art, language, and culture like modern Ukraine (Rusina 2007). Trypillians date back to 5400 BC and the copper age (Ciuk 2008). Trypillian ruins were found in Trypillia which is south of Kyiv (Ciuk 2008; Fund for Research on Ancient Civilizations 2010). The Trypillians were the first people to bake bread and melt metal (Ponomarenko 2013).

Trypillians are believed by archaeologists to be the ancestors of Ukrainians. In Western culture, the fine artist is considered "the real artist," while applied artists were more and more specialized in commercial endeavors such as children book illustration, journal illustration, and medical illustration (Getzels and Csikszentmihalyi 1976). "Creative work is the concrete statement of existential problems which previously were experienced only as diffuse tensions" (Getzels and Csikszentmihalyi 1976, p. 243). However, in Ukraine and other countries where Ukrainians have emigrated to, folk art as well as folk music is prominent, in which is art work and music that are by the people and for the people while still addressing existential problems that are shared by the Ukrainian people. Furthermore, Picasso stated, "An artist unfamiliar with the achievements of the Trypillian civilization cannot consider himself a real artist" (Fund for Research on Ancient Civilizations 2010, back cover). Pablo Picasso, Taras Shevchenko, Alexander Archipenko, and numerous Ukrainian folk artists may have been influenced by the Trypillian civilization (Fund for Research on Ancient Civilizations 2010).

9.5.2 Taras Shevchenko: Ukrainian Hero Especially for Modern-Day Ukrainians

Taras Shevchenko (9 March 1814–10 March 1861) was born in Kyiv Governorate, in the village of Moryntsy (today Cherkassy Region) (Shevchenko and Stepovyk 1984). Shevchenko was of Cossack descent, which are known as brave Ukrainian warriors. As a Ukrainian patriot, Shevchenko had pioneering poetry writings and artwork that influenced Ukrainian politics, dancing, and acting and described peasant life of ordinary people in Ukraine. Shevchenko fought against social and national oppression of his people (Shevchenko and Stepovyk 1984). In *Taras at Night,* Shevchenko describes the spirit of the Cossack specific to Ukraine (Shevchenko 1964, p. 60).

> A minstrel sits at the cross-roads,
> On his lute he's playing;
> Around him lads and lassies go—
> Like red poppies swaying.
> The minstrel plays and sings away,

Chanting out the words,
How the Cossacks fought the Poles,
The Muscovites, the Horde.
How all the village gathered there
One Sunday morning early;
How they buried a Cossack young
In a verdant gully.
The minstrel plays and sings away—
Making sorrow laugh….
"Once there was a Hetman-state,
Ended now its sway!
Once there was our own self-rule,
Now, we'll rule no more.
Now that the fame of Cossack glory
Enriches memory's store!
Oh Ukraine! Oh Ukraine!
Motherland so dear to me.
When I ponder on your fate
My heart weeps bitterly!

Shevchenko wrote in the Ukrainian language that was spoken by the people. The content was humanistic and promoted unity (Kirilyuk 1964), while promoting national independence for Ukraine (Rubchak 1980). This led toward his influence on Ukrainian folk poetry (Kirilyuk 1964), Ukrainian folk music, and Ukrainian folk art. Shevchenko expressed the thoughts, feelings, and aspirations of the broadest sections of the Ukrainian people which lead toward increased nationalism in Ukraine (Kirilyuk 1964) Shevchenko's creative output can be understood by his wide-ranging plans (Ievshan 1980). Shevchenko intended for his work to be useful for society. Shevchenko was able to synthesize various moments and feelings and use their passion and power (Ievshan 1980). In a well-known Ukrainian poem, Shevchenko illustrates his feelings and their passion that many Ukrainians shared with him and have continued to experience for years in his poem *Oh Thoughts of Mine* (Shevchenko 1964, p. 30).

Oh thoughts of mine, oh thoughts of mine,
Grief we bear together!
Why stand you in such sad black lines
To the paper tethered?…
Why has the wind dispersed you not
Dust-like into flight?
Why sorrow overlay you not
Like her babe at night?

Currently in Ukraine, there are many monuments, universities, and libraries honoring Taras Shevchenko and his legacy. There is growing interest of multiple generations in Shevchenko's legacy for profound revolutionary-democratic trends of his creative works (Shevchenko and Stepovyk 1984). Furthermore, with the current oppression and aggression from Russia, Yanukovych, and Putin, this history of Ukraine's oppression is vital, especially since religion and war may be stimulants for creativity (Runco 2007). Furthermore, existentially we struggle and fight death through creativity (May 1975). Bergoglio and Skorka (2013) stated that the three worse genocides were (1) of the Armenians by the Turks, (2) of the Ukrainians by Stalin, and (3) of the Jewish people and other priests, Polish, Ukrainians, Russians, and other cultures including sexual orientation minorities and the physically and psychologically disabled by Hitler. In the Holodomor, Stalin starved over 9 million Ukrainians by taking their own food from them, starving them, and putting them in trains to Siberia where they starved and froze to death in the extreme cold and even engaged in cannibalism while trying to survive. Recent numbers reflect as many as close to 10 million Ukrainians suffered from genocide including men, women, and children (Bilinsky 2013). Bilinsky (2013) also states that in the case of genocide, not only were individuals destroyed, but the goals were also to destroy the Ukrainian culture and the Ukrainian nation. Terror by famine was used which led to mass incidents of cannibalism and food made from human meat (Kardash 2007).

Churches were transformed into prison camps; Nikolskaya Church and Uspenski Cathedral had bunks four tiers high (Solzhenitsyn 1974). Priests were forced to renounce the priesthood and even had their genitals sawed (Kardash 2007). When nothing was done (regarding renouncing the priesthood), these priests were then imprisoned and exiled to forced hard labor camps (gulags) also described as rural Arctic concentration camps in Siberia and northern Russia (Kardash 2007; Solzhenitsyn 1974). In prison, priests, Christians, and other prisoners (both men and women) would chop down trees. Men, women, children, priests, Christians, engineers, and others were imprisoned in camps; if a child would steal potatoes due to starvation, the family would have their prison sentences extended by 8 years (Solzhenitsyn 1974). Prisoners would work for food and be treated without dignity like animals. In addition, many prisoners died from cold and hunger (Kardash 2007; Solzhenitsyn 1974) before their sentences were served of 10–15 years (Solzhenitsyn 1974). Majority of prisoners were Ukrainians, but there were also people from the Caucasus and Central Asia (Kardash 2007). Even Stalin stated, “Pay *more serious attention* to Ukraine” (Pyrih 2008, p. 41).

Krauthammer (2014) stated that Obama has written off Putin’s aggression with indifference and inaction. Inaction is unjust; we should provide military assistance (radar systems, defense weapons) and support Ukraine’s needs for democracy since this is “the right thing to do” (J. Martin, personal communication, September 30, 2014). In the opinion of the author, assistance and aid from the United States of America, the European Union, and the United Nations to Ukraine is still needed to date. President of Ukraine Petro Poroshenko stated not to be silent in times like these in his address to a joint meeting of Congress in the House Chamber on September 18, 2014. Speaker of the House of Representatives Boehner invited Poroshenko to speak to this joint session of Congress. Poroshenko received strong support from Congress as well as at least 10 standing ovations (UNIS 2014). Poroshenko asked for United States of America help to stand the ground for the free world. Poroshenko stated that Russia's actions not just threaten Ukraine, but world stability (UNIS 2014). Russia's actions and Ukrainian requests for (1) military assistance (2) more severe sanctions against Russia and (3) support Ukraine's Parliamentary elections on October 26, 2014, are received by Obama with a tepid response during his White House meeting (UNIS 2014).

Poroshenko, in his address to the United States Congress, offered to help fight lies of the propaganda by Putin. "Russification" undermines the creative potential and whole society (Simonton 1997), and Stalin and Putin have been trying to attack the Ukrainian people and the Ukrainian culture. However, Ukrainians are strongly united through their culture (Ponomarenko 2013). Just as theorists have addressed the benefits of creative expression by Holocaust survivors, creativity can lead toward new novel responses to such situations to gain greater meaning in their lives (Corley 2010) which is also true in the current Ukrainian crisis. Poroshenko stated, "I urge you not to let Ukraine stand alone in the face of aggression" (Bihun 2014, p. 11) and stand up for the promises made in the Budapest memorandum by Russia, the United States of America, the United Kingdom, France, and China (Press Office of the President 2014).

In 1847, Shevchenko stated, "Love your Ukraine, In the last terrible moment…Pray to God for her" which is still relevant today. Even in 2014, Ukrainian priests have been imprisoned. Protestors that often pray before peacefully and civilly protesting were later tortured and murdered. The 2013 and 2014 Revolution of Dignity to join the European Union and stop the ways of communism with Russia was lead with Ukrainian pride. Slava Ykrainy! Heroyam Slava! translates to Glory to Ukraine! Glory to the Heroes! (Adrukhovych 2013). Even in the Bible in St. Paul's letter to the Galatians (in Galatia which was the north central region of Turkey directly south and central of the Black Sea), "To God Be the Glory Forever and Ever!" is stated early in history since this region was key in Asia minor, also integrating the East and West, like Ukraine. However, these prayers from the New Testament continue to be relevant to Ukrainians (both Orthodox Christian and Byzantine Catholic) and other Christian people today.

Over 100 protestors supporting the West, democracy, freedom, and independence were murdered by snipers alleged to be working for the Ukrainian government under Yanukovich, ranging from children, women, fathers, and grandfathers to priests, university professors, students, engineers, poets, entrepreneurs, artists, and musicians. Brutality against the people of Ukraine is still present today in 2014.

For example, Yuri Verbitsky was 51 years old and worked in the Department of Seismology in Lviv. Verbitsky was abducted from the Olexander Clinic along with activist Ihor Lutsenko in the morning of January 21, 2014. His body was found on January 22, 2014, in the vicinity of the village Hnigeh in the region of Borespil (airport) in the oblast of Kyiv with signs of torture. From a video testimony of friend of Roman, Yuri's legs were broken, bones were visible, spine was blue, face was beaten, and ribs were pushed out in the right side through the skin because they were probably broken. Official cause of death is overexposure to the cold.

Reminiscent of events during the Soviet era and its KGB secret police, numerous Ukrainians have disappeared over the previous year and may have been murdered. These disappearances are in addition to the over 100 Ukrainians who were killed by snipers during the Maidan protests. However, Ukrainians continue to fight for democracy.

Khvylovy (1986) reflects that as early as 1933, Ukraine was influenced by Europe and even the French Revolution. These influences are not only political but are also cultural. Poroshenko in his address to a joint meeting of Congress on September 18, 2014, also stated "Live Free or Die" which was prominent in the United States American Revolution as well as the Maidan Revolution of Dignity. Poroshenko complemented the millions of Ukrainians that have been fighting for freedom, democracy, European values, and rule of law. Poroshenko stated that human dignity makes Ukraine's heart beat (Press Office of the President 2014). Poroshenko stated he would not compromise the democracy, sovereignty, liberty, and independence of Ukraine since Ukraine has gained again since August 24, 1991.

Taras Shevchenko represents the Ukrainian struggle and fight for democracy, independence, and sovereignty which is still relevant today! A Taras Shevchenko monument dated 1959 located in Washington, DC was "Dedicated to the liberation, freedom and independence of all captive nations" (Bilinsky 2013, p. 36). Artist and engineer Alexander Archipenko sculpted a Taras Shevchenko head portrait in 1933 (Archipenko 1960) which is a monument in the Ukrainian Cultural Gardens in Cleveland Ohio, United States. Shevchenko (Ukrainian born) is depicted by Archipenko (Ukrainian born, United States immigrant) with the author (American born, first-generation Ukrainian immigrant) demonstrating various types of immigration and emigration that is highlighted throughout the various Cultural Gardens in Cleveland, Ohio, United States. Charyton visited these cultural gardens in May 2013.

Charyton is wearing a shirt with a Tryzub or trident which is the emblem of Ukraine. Although objects have a systematic logical approach to demystify and understand the creativity of the Trypillian civilization, we may still know little about beliefs or the religious culture of the Trypillian people (Fund for Research on Ancient Civilizations 2010). However, Trypillians may have also had the existing world with the concealed world (Ponomarenko 2013). The modern-day symbolic meaning stems from St. Volodymyr Velyky (St. Volodymyr the Great) from 950 AD using the Tryzub to keep away evil and spread Christianity. Modern-day meanings stand for freedom, democracy, sovereignty, and liberty for Ukraine with the Tryzub on Ukrainian flags (which are blue and yellow with blue on top). Furthermore, the Tryzub unifies the Ukrainian people (Ponomarenko 2013, A. Essenhigh, personal communication, June 21, 2014).

9.5.3 Alexander Archipenko: Bridging East and West as Well as History with the Modern

There are artists, such as Alexander Archipenko (May 30, 1887–February 25, 1964) that is also influenced by science, engineering, and other disciplines and was born in Kyiv, Ukraine and emigrated to the United States. Archipenko was also an engineer who used innovative methods for creating art work, called *Archipentura*, which are movable paintings (Archipenko 1960). Archipenko dedicated this invention to Thomas Edison and Albert Einstein. *Archipentura* is a machine to produce the illusion of motion. The movement produces a psychological reaction that is also spiritually, creatively, and aesthetically significant (Archipenko 1960). Archipenko used constructions and sculpto-paintings to form a stylized effect that would be a focal point from multiple windows (Michaelsen et al. 1986). Some coin Archipenko's contributions to art as "metaphysical cubism" (Archipenko et al. 1985, p. 6).

Archipenko (1960) describes Genesis, the act of creation, as inspiring his artwork. Interesting enough, engineer stems from the Latin "Ingeniatorum" meaning "ingenious" with "gen" referring to the act of creation or "Genesis" (Allen and Self 2008; Charyton 2013, 2014b). Archipenko (1960) shared roots as an artist and engineer and was influenced by philosophy and spirituality. Archipenko (1960) stated that creative potency is about awareness of these factors that are mostly metaphysical in origin. Furthermore, Archipenko elaborated that for our creative purposes, we use psycho-physiological factors that evolve in the metaphysical and spiritual forms that are expressed through art. The form-changing abstract creative forces are in the cosmos. Archipenko might argue that both science and art find these properties.

Archipenko did not neatly fit in a box. Archipenko's style integrated ancient folk art, cubism, and abstract modernism in his own unique style. Also, like in the Renaissance, persons like Da Vinci excelled in engineering, art, political strategy, and making musical instruments. There were heightened times of accelerating in multiple areas or domains. Archipenko (1969) describes his work as spiritually, esthetically, emotionally, and creatively, the form–color has rich variations as in a symphony; this musical phrase interfuses and evokes multiple reactions in the individual. Archipenko reflects that contemporary conceptions of creative transformations of the work give a spiritual aspect.

Archipenko (1969, p. 36) reflects on his own cultural identity in essence with the unification of East and West:

> My ancestors, the same as the Russians, availed themselves in the past of Byzantine and Oriental influences. I like Byzantine and Oriental art,
> in fact, all that is of genius in every country and of all times, and my real
> tradition is found everywhere—in the genius of my human creation.
> There is no nationality in my creations. In that respect, I am no more
> Ukrainian than I am Chinese. I am no one person.

In some ways, Archipenko's approach is much like Japanese Zen Buddhism. Archipenko stated in his approach, "…we accept the fact that less can make more, that space can miraculously turn into form" (Archipenko 1967, p. 7). Kuh speculates that from beginning to end, Archipenko (1967) remained a Ukrainian man that was closer to the near East than West. Kuh suggests that Archipenko's approach lead to numerous contributions in the history of modern art.

9.5.4 Ukrainians Today

Many Ukrainian emigrants in the United States often pursue careers in science while being brought up active in the arts. There is keen interest in the sciences, the arts, politics, and religion. For example, it is not uncommon for an engineer to be brought up professionally dancing, singing, and playing music, or a physician to also be brought up dancing, singing, and playing music (L. Rakowsky, personal communication, February 3, 2013; A. Rakowsky, personal communication, February 3, 2013; A. Charyton, personal communication, May 8, 2013). Ukrainian dancing is an expression and exchange of the Ukrainian culture. For example, Voloshky (2014) Ukrainian Dance Ensemble combines Ukrainian and American aesthetics, drawing upon classical, contemporary, and folkloric styles to create powerful transcultural programs that cross-pollinate diverse audiences. Acting in plays, singing, practicing, and performing music (piano, violin) are also very common for Ukrainians in addition to drawing and mathematics (A. Charyton, personal communication, May 8, 2013; A. Melnyk, personal communication, September 6, 2014). Learning additional languages in elementary school in addition to Ukrainian and English are also common (A. Charyton, personal communication, May 8, 2013; A. Melnyk, personal communication, September 6, 2014). Reading traditional poetry and listening and performing traditional music is a part of the culture. This is also true for both genders of offspring. Although interests in the sciences and the arts may also exist in other European and Asian and other cultures, in Ukraine, there are more cases of people with cultural interests that tend to excel in more than one area or multiple disciplines. Rather than being a jack of all trades and master of none, there are Ukrainians that are masters in more than one area, just as in the Renaissance. For example in the Renaissance in Italy, DaVinci was attracted to engineering and used his interests in science, mathematics, and engineering to influence his painting (Robinson 2010).

9.5.5 Hnat Hotkevych: Another Influential Polymath

For example in Ukraine, Hnat Hotkevych (December 31, 1877–October 8, 1938) also excelled in multiple areas. Hotkevych was a prominent writer, composer, theatrical, and political figure (Kubijovyc 1984; Zhukovskyj et al. 1955). As a musician, he was a composer and wrote a manual on how to play the Bandura in 1909 and again in 1930 called “Manual Playing Bandura,” the symbolic Ukrainian folk instrument that is distinct to Ukraine. His compositions included “Bayda” and “Storm on the Black Sea.” In 1912, Hotkevych founded the first Ukraine workers theater where over 50 shows were performed in 3 years. Two of his plays became movies called *Soul of Stone* and *Dorbuch* (N. Turchyn, personal communication, April 21, 2014). Hotkevych was also a teacher and interpreter and translated many books into Ukrainian (M. Mudrak, personal communication, May 17, 2014). Hotkevych was also the editor of the literature journal *Herald Culture and Live* (Kubijovyc 1984; Zhukovskyj et al. 1955).

9.5.6 *Ivan Franko: Influential Legend*

Ivan Franko (August 15, 1886–May 31, 1916) was a Ukrainian peasant that received his PhD in philosophy and became a spokesperson for his people (Franko and Rich 1973). Franko excelled at writing poetry, sonnets, novels, short stories, plays, and children's works in addition to philosophical works. Franko integrated philosophical and patriotic poetry to address fundamental, social, and humanistic problems for Ukrainians (Franko and Rich 1973). Franko also translated literature from other cultures into Ukrainian for the Ukrainian people. Franko wrote in *Dedication* words that are still relevant to Ukrainians today:

> So in your mane to ev'ry village
> Let this, my song, itself employ
> To all those gloomy nest of tillage,
> Where woe awaits—a word of joy.
> And may it there, ablaze, enliven,
> The soul that's free, and free from fear,
> Whose all to love of man is given,
> And holds the truth o'er all as dear.
> (Franko, circa 1900, trans. Tatchyn 1979)

Franko went from being a peasant to writing a wide array of influential literary repertoire that is truly inspiring. Again, he also discussed existential problems that Ukrainians face, even today.

9.6 Can People Still Be Exceptional in More Than One Domain Today?

Some may state that these were activities from the Renaissance which are no longer valid today, yet the integration, synthesis, and unification of knowledge (Wilson 1998) are only beginning to prosper. Simonton (2009) acknowledges that there may be diverse domains of creative ability. In the case of Ukraine, there seems to be cultural and political circumstances that have lead toward creative abilities in diverse domains simultaneously in the same person. This may also be true for high-impact scientists involved in diverse modes of interests, constellations of interests, and hobbies (Charyton et al. 2014, 2015; Simonton 2009).

Today, more and more people are specialized and more often are discouraged from multiple interests. However, in one of the author's psychology of creativity classes, 62 % of the students in this class have a major other than psychology, a dual major (where both areas are not in psychology), or a major (other than psychology) in addition to having a psychology major. More specifically, students were 38 % psychology majors, 41 % other majors, and 21 % psychology and another major combined (out of 76 students). In sum, 62 % of students in this class had a major other than psychology by itself, with another different major other than psychology, or in combination with psychology. The course was designed as an upper division elective for psychology; however, the course has broad appeal to students in philosophy, medicine, neuroscience, business, law, economics, entrepreneurship, physics, astrophysics, computer science, engineering, and chemistry among other majors and minors. The manner in which the author designed the course was applicable to various disciplines. Many entrepreneurs were also in the class and learned about practically every discipline in psychology as well as other fields and their relation to creativity and innovation.

Students need to be encouraged to have broad interests or multiple interests and derive synthetic combinations, which are aspects of creativity (Runco 2007). If students have more options to unify their interests, greater diversity can stimulate creativity and led toward increased innovation. Tatu (2013) suggested that educators need not to talk only to people in their own discipline, but to other people in other disciplines as well. Cross-pollination can truly benefit all aspects of academia (teaching, research, and service) as well as the application of creativity and innovation in society.

Furthermore, science, technology, engineering and mathematics (STEM) have also been expanded to including STEAM—additionally adding *arts* and STEMM—additionally adding *medicine*. Psychology has also been discussed as a STEM option (and can likely fit with STEAM and STEMM integrating other disciplines). With financial constraints, arts and music programs may be the first to be dropped from educational programming in K-12 education. Both the sciences and arts and their integration are key toward enhancing creativity and innovation in our society—locally as well as globally.

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Chapter 10
Reflections of Our Conversation Among the Cultures in Science and Art…

Christine Charyton, Ted M. Clark, Alejandra Ferrer, Anne Harding, Herbert Newton, Robert J. Perry, Jill Francis and Segun Osiniusi

C. Charyton (✉)
Department of Neurology, Ohio State University Wexner Medical Center,
Columbus, OH, USA
e-mail: charyton.1@osu.edu; christine.charyton@gmail.com

T.M. Clark
Departments of Chemistry and Biochemistry, Research Experiences to Enhance Learning (REEL), Ohio State University, Columbus, OH, USA
e-mail: clark.789@osu.edu

A. Ferrer
Nationwide Children's Hospital, Columbus, OH, USA
e-mail: alejandra.ferrer@nationwidechildrens.org

A. Harding
Ohio State University Wexner Medical Center and James*Care* Survivorship program. Ohio State University Medicine and the Arts Board, Medicine and the Arts Roundtable, Columbus, OH, USA

H. Newton
Departments of Neurology and Neurosurgery, Ohio State University Wexner Medical Center and James Cancer Hospital, Columbus, OH, USA
e-mail: herbert.newton@osumc.edu

R.J. Perry
Department of Physics, Ohio State University, Columbus, OH, USA

J. Francis
Logistics Business and Entrepreneurship, Fisher College of Business, Columbus, OH, USA

S. Osiniusi
Department of Psychology, Columbus, USA

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10.1 Creativity: Conversation Reflection

Herbert Newton

It was very clear from the conversation among all of the dedicated and talented authors of these book chapters in this book that creativity was extremely important in all of their fields, even though each of the disciplines was very different, ranging from Art to Music Therapy, to basic fields such as Theoretical Physics and Chemistry, and more clinically oriented fields such as Theoretical Physics and Chemistry, and more clinically oriented fields such as Psychology and Neurology. In each field, it was clear that basic creativity was critical for that field to advance in terms of new research, potential paradigm shifts in large spheres of the field (e.g., Einstein and quantum mechanics in Physics), and to allow for improvements within society as a whole. Even in the purely artistic fields, such as Art and Music, huge leaps in creativity have been necessary for major paradigm shifts to occur. In the Art world, the work of the Impressionists is a perfect example of this kind of creative shift and change that can totally alter the world landscape of a given field. Similarly, for the world of Music, huge creative shifts have occurred over time. For example, when the Age of Rock and Roll was instigated in the 1960s, when young musicians in England discovered the blues music of the American South. Creativity is paramount in these kinds of "leaps ahead" in any given field. However, it is also important for many day-to-day activities that people engage in, that are not recognized as being overly creative, such as teachers figuring out how to "get through" to an unmotivated student, parents helping their children to enjoy reading, and the many ways to apply the tools of modern social media.

I was also struck by the differences in the fields, in terms of how creativity was used or applied. In the Artistic fields, such as painting, drawing, and sculpting, the artist is often being creative for its own sake, to "create a vision in their mind", and bring it to life in solid form. The same is often seen in Music, where a musician will write songs and create music—often without any regard for appreciation or recognition—because that is what "he or she was compelled to do". In the hard sciences such as Physics, Chemistry, Engineering, Computer Science, and Mathematics, creativity is used to advance the current "state of the art" in a given sphere of the field, sometimes causing massive shifts in the way society—or even the world—thinks about, relates to, or uses, a given topic. Although different in their approach, both forms of creativity are vitally important for any society to reach their full potential and maximize functionality for all their citizens.

It will be vitally important for the United States of America (USA), Canada, Western Europe, and other leaders of modern society to continue to study—and to nurture—Creativity in various spheres and among their citizens. This will be critical if we are to advance as a healthy, viable, "world culture" that can handle—and conquer—the challenges that are yet to come over the next 50–100 years, including global health, increasing food production, global warming, modernization of 3rd World Countries and Societies, and many other pressing issues. Creativity and innovation in our scientists, physicians, teachers, and engineers will be the only way to continue on the path of societal, worldwide progress.

10.2 Conversation Reflection

Alejandra Ferrer

It was incredibly inspiring and eye opening to discuss creativity with professionals working in what I had initially perceived as distant and unrelated disciplines. In my own work as a music therapist, I rarely think about or conceptualize creativity. Operating primarily from a well structured, predetermined, behavioral model, creativity, freedom, and improvisation often occur in a spontaneous manner, many times client-led, and supported and "taken further" by the music therapist. Is this how the creative process typically begins? Or do individuals operating from different philosophical paradigms where creativity is central operate differently? While I may not view my work as "highly creative," others may evaluate my work and immediately identify high levels of creativity and innovation, from helping a client problem solve and make difficult decisions through songwriting coupled with verbal therapy, to using live, patient-preferred music to decrease the stress and anxiety of a hospitalized child. The therapeutic techniques used in music therapy are *innately* creative. It may just be that creativity is so ubiquitous to the music therapy process that one rarely gives it much thought and attention.

Do the various contributors in this book think and feel similarly? Or do they place greater thought on the creative process within their respective fields? Do they *decide* to approach their work in a creative fashion? Do they *set up* situations in order to allow room for creativity? Is creativity even possible? Is it safe? Reflecting on our conversation, I have been left with more questions than solid, conclusive answers.

One does not immediately assume that creativity is as prevalent and central to the sciences as it is to the arts. Speaking from a stereotypical perspective, people often view musicians, dancers, and artists as highly creative people. The same is not often thought of chemists, physicists, and medical doctors. It appears that some fields are *explicitly* creative, while others are not as easily placed in this category. This said, speaking with the various contributors of this book, it became evident that creativity was an important aspect of their work; and that they had reflected on various aspects of creativity and innovation in order to enhance their effectiveness, knowledge, and practice. It was clear that they valued taking risks, stepping outside the box, and pushing the boundaries of what is "known," "accepted," and perhaps perceived as "obvious" further.

Following our discussion, I am left with the thought that it may just be that creativity is in the "eye of the beholder;" or in the eye of a complete, unknowledgeable outsider who is fascinated with what they are witnessing. What is most clear is that if work is approached with passion, thoughtfulness, and curiosity, creativity is possible and can be ever present.

10.3 Reflection: Creativity and Innovation Among Science and Art—Response from an Art Therapist

Anne Harding

It became clear to me early in the conversation on creativity that when you bring together a chemist, physicist, an MD, psychologist, and a music therapist and art therapist in a discussion, there are likely to be some semantic differences. Everyone came to the table with their own working knowledge of what it meant to be creative in their field, both as individuals and as a body of study. Indeed, even the word creativity appeared to hold noticeably different definitions among the panel of authors. It was generally agreed upon that you need to have a basic set of skills to be "creative" on a grand level, yet the scientist, Dr. Clark, held that even prior to having skills, discoveries could be made. For those in the therapeutic areas of study, creativity did not necessarily mean something never before conceived such as a groundbreaking medical discovery or a "Eureka" scientific moment, but the creative process of helping other individuals discover something unique about themselves in the process of therapy. Hence, the discussion volleyed back and forth between what creativity meant, who would benefit and what basic toolkit or skills were needed to achieve creativity.

Additionally, the process to achieve creativity seemed to vary among the authors. Some seemed to feel it was a step-by-step process and others felt it was something stumbled upon. The chemist on the panel stated that he would be product-oriented and felt that it might be difficult to focus on the process to the exclusion of the product. He stated that it might be difficult to put off evaluation and judgment. I find it interesting to discover that what can be hallmarks of an excellent scientist might also stand in the way of being open to the process. Similarly, a fine artist such as an illustrator, for instance, sometimes has difficulty letting go of a finished product to move into process. Conversely, for myself as an art therapist, I might find it difficult to work within the scientific structure or within strict medical procedural guidelines without feeling stifled by the rules or laws that guide the process. In music and art therapy, patients are often encouraged to focus on the process and not the product with the creativity being inherent in the process and the product not necessarily being an important end result.

The differences in the various fields became even more apparent when the discussion turned to the differences between classical musicians and jazz musicians. As the music therapist, Dr. Ferrer talked about how both musicians might feel they were creative even though a jazz musician may be more improvisational and a classical musician would rely more on simply playing the score creatively, as in with more feeling. Dr. Newton added in that different parts of the brain were activated in the jazz musician when he or she were improvising indicating that this signified more creative action. This knowledge applied to research in both neuroscience and creativity in music has much significance, but again what is the definition of creativity being used? Application of the neurosciences in art therapy is also growing rapidly and has already changed the field significantly in dealing with trauma, early childhood violence, autism, and eating disorders. I advocate, however, that the true meaning of creativity or perhaps the more important definition of creativity in the therapeutic fields is of assisting the patient or participant in discovering new ways of perceiving the self, new ways of being in the world hence paving the way for lasting change.

In addressing flow and how it is achieved and what squelches flow, it appeared that each group member was more easily able to relate and also to apply to their personal lives. Although in discussion, Dr. Clark mentioned the need to apply a scientific application to the concept. It appears the things that most assist each of us in our respective fields can also potentially hinder us when it comes to the paradigm shift necessary when combining the arts and science.

10.4 Reflection

Robert J. Perry

(1) When I first prepared a lecture on creativity, I discovered how difficult it can be to define creativity. Even after narrowing my scope to theoretical physics, I realized that distinguishing creativity from discovery is not simple. Stumbling upon something unexpected is not necessarily creative but it can be. Possibly my most creative piece of research was accidental. Being impatient, I made up what I thought was a typical approach to solving Renormalization Group problems. When I presented it to Kenneth Wilson, who received the Noble Prize for Physics in 1982 for his work on the Renormalization Group, he told me that I had gotten it completely wrong. However, what I had accidentally invented provided a new tool for solving inadequately constrained Renormalization Group equations, which we dubbed coupling coherence.

(2–4) We pride ourselves on teaching students how to think like a physicist. Whether we succeed or not, our processes are intrinsically creative, as is all of basic research. As outlined in my article, our task is to develop experimental tools that allow us to map raw data onto mathematical descriptions (e.g., position as a function of time) and to then create mathematical equations that provide models (never exactly correct) which fit the data. The equations are not the phenomena. They are found nowhere in the world and they are invariably found to be wrong as our experiments improve. But the sequence of increasingly precise and universal laws has led to an understanding of essentially every piece of data that physicists have amassed over centuries of work. This understanding has led to practically every invention upon which modern society is built.

(4) Analogy is probably the most important inspiration for creativity in theoretical physics. Many, probably most, great breakthroughs are at least partially grounded in analogies. An examination of the data, which is often far removed from the actual observation, can inspire a physicist to think of something else. The harmonic oscillator, a simple particle on a spring, has inspired everything from

Einstein's models of solids to Heisenberg's formulation of quantum mechanics. The analogy is not obvious and often fails to inspire anyone else but it gives the creative mind a starting point from which to leap.

(5) I like to dive into a problem and spend as many waking hours as possible thinking about it. A good problem is always in the back of my mind. Sometimes I go to sleep thinking about something and wake up with a new idea, or something new just comes to mind while I'm in the middle of a long run. At times the new idea arrives almost fully developed. When progress becomes difficult, I try to isolate what is essential or identify a paradigm that contains only the basic parts of the problem. Jarring my mind into a new line of thought is sometimes just simply a matter of telling someone else about the problem. I'd guess that my internal model of how someone else is thinking helps me find a new approach.

(8) It seems unlikely that the creative process in abstract art is the same as in theoretical physics but I remember running into an artist in Paris who was excited to tell me how new ideas in physics had inspired much of his work. He would study a new discovery and take from it an impression that could be expressed visually. I'm sure that the reverse happens, where a piece of art somehow stimulates a physicist to come up with a new idea that simply fits the problem as hand. I can't help but think that there is something truly universal about creativity.

(12) Creativity can be found everywhere in the sciences. I believe it happens daily in the life of a scientist that it is the lifeblood of our progress. There are minor acts of creativity required to set up a new problem of broad interest and major acts required to advance a whole field. In our introductory classes, we throw out ideas which required twenty years for some of the most brilliant minds on the planet to invent, then we expect students to almost immediately "get it." But students effectively need to re-invent these things for themselves. They are often reverse engineering the basic ideas from what are little more than clues which we provide in our lectures. The fact that students must be creative to understand new material is typically not appreciated and education suffers.

(14) Without creativity, we're basically stuck where we are, stuck with our current methods, our current ideas, our current products. You can take almost anything of value, products, ideas, works of art, and their history is one of creative steps and breakthroughs. That progress leads through many fields, it's highly nonlinear and is never a single line. It's better to think of streams leading into rivers, leading into oceans, than to think of one person following a path. We're comfortable with the idea that a simple product like a pencil requires an amazing array of work from mining through final distribution, but we don't often appreciate that every creative breakthrough rests on an even more complex array of prior creative work in a vast network of different fields. When our students are trying to understand how they will fit into our economy and contribute value as part of a job, we do them a terrible disservice whenever we act as if they might simply end up using tools created by others to go through motions invented by others to produce products invented by others. The carpenter who manages to avoid creativity is a poor craftsman.

(15) I don't think that it is very productive to rank different types of creativity or creativity in different fields. The mind brings something totally new into this world

and the processes it uses are seldom obvious but often amazing. And one form of creativity becomes the base for another completely different form. The Renaissance only happened after scientific research provided a base of new materials for artistic work. The history of music hangs on a skeleton of musical instrument invention, which is largely scientific. Communication and the free exchange of ideas are critical for the creative advance of all science and art. Inspiration moves between fields like some form of energy that can be harnessed to any purpose.

10.5 Reflections on Creativity

Ted M. Clark

Conversation with others who have reflected on the role of creativity in their discipline, careers, and lives reveals that many attitudes and ideas adopted by chemical educators resonate with the views of those in other fields such as medical research, theoretical physics, or music therapy. This is not surprising, as the view of creativity described in the chemical education literature is multi-faceted, informed by the actions of chemists and other scientists, the work of philosophers and historians of science, psychologists, and educators. While it would be presumptuous to say that creativity has been "figured out", it does seem that creativity has recurring characteristics cutting across disciplinary boundaries that researchers and historians have identified and that these common features of creativity have been noted by chemical educators.

Even though participants were drawn from different fields, everyone referred to the practices, norms, and paradigm in which they functioned. The notion that chemists solve problems within an accepted framework that includes opportunities for creative decision making was echoed by everyone as they reflected on their own problem solving. The idea that one may accumulate experiences that build up, perhaps sub-consciously, and these suddenly burst upon the scene to provide new insights was also shared. In rare instances, these may even lead to a radical transformation and the genesis of a new paradigm.

Another common theme was the notion that creativity benefits from environments that are not overly judgmental or evaluative, like brainstorming. An interesting perspective on this topic was voiced by those participants who use creativity therapeutically. In their discipline, creativity is not primarily about problem solving. Instead, it is an activity with intrinsic value that focuses on participation and self-expression. In this setting, one does not generate a list of ideas to solve a particular problem, but instead considers more broadly how to encourage individuals to act creatively and benefit from these actions. This may produce a sense of "flow" as one becomes lost in the moment, fully focused with the task at hand.

A distinction, therefore, seems to be present between those who are creative problem solvers and those who use creative activities as a resource for improving the well being of others or themselves. A researcher, like a scientist, seeking to address a problem may generate ideas that range from conventional to innovative. A creative, novel solution has value over the conventional solution if it is a superior way to address the problem. In contrast, one who uses creativity therapeutically is far more interested in the process of creativity, producing benefits from acting in the moment creatively. It is not entirely clear where to place an artist like a painter, poet, or composer in this discussion. Is an artist's product, be it a painting, sonnet, or symphony, a solution to a problem? Or is it rather an act with value unto itself that affects the creator first and foremost? Perhaps, such a distinction breaks down with artists resting in both camps.

Finally, this prompts the question of whether scientists and others who engage in creative problem solving benefit not just from finding a solution, but also by simply engaging in a creative process. To the extent that creativity is intrinsically beneficial, this provides even greater motivation to reflect on science instruction across the curriculum and consider ways to enrich student experiences by challenging them to think and act creatively. This, of course, also requires educators to move beyond traditional constraints, guided by a vision that values both the creative process and the acquisition of content knowledge. As Einstein stated, "The value of a college education is not the learning of many facts but the training of the mind to think." This notion should be expanded to recognize that "training the mind to think" *creatively* is an attribute with inherent lifelong benefits.

10.6 Conversation Reflection

Christine Charyton

In reflection of our conversation, I noticed that we had a diverse body of participants from across the university in medicine, science as well as in creative arts therapies. Overall, I believe most of us felt that we related well with each other and shared more in common with each other than had differences.

However, we did reflect on having a couple of camps. One camp pertained to the application of science and art while the other, focused on research—both basic and applied. However, we identified that these two camps also overlap. Primarily, there is overlap in relation to neuroscience that advances the arts forward.

The camp of research that was striking involved both basic and applied research. Although distinct from each other, these two areas may be driven by a larger societal impact. On a much larger level, society may judge a contribution to make an impact and time may play a factor. Societal acceptance of deeming a contribution as creative or innovative may take many years even until the gatekeepers change. Societal implications are keys for research contributions, but may also be equally expressed in the arts and sciences as well as other disciplines. Furthermore, a contribution may not be appreciated initially. Instead, the contribution may take many years in order for more people to catch on.

The other camp we identified was regarding clinical applications to improve people's lives. These professions included medicine, neurology, psychology, art therapy, and music therapy. On an individual level, the act may take less time to be considered creative and innovative. However, time may also play a significant role at the individual level. Acceptance may take time on both individual and societal levels. However, on an individual level, there may not be a need for any comparisons at a society level. One may deem their own work to be creative and innovative without comparisons with others, but rather in comparison with their own past work in their developmental path. These two distinctions still do overlap. There are cases where both the individual and societal levels overlap. For example, a creative act by the individual may be innovative to both the individual and society—which may be ideal for a larger impact. Furthermore, research and clinical implications advance these professions, fields, and domains. However, on an individual level, there should be more room for individual differences to be appreciated. On the individual level, one may also appreciate the creative process and journey rather than only the end result, product, and outcome.

Science and art complement each other especially through application. Through the application of creativity, we have innovation. Through application, we integrate theory and practice. Through this higher order processing, we have a highly significant impact on society to enable and enrich people's lives. This integration was commonplace in the Renaissance, but this integration is still true of other cultures and may be impacting our current era and near future toward the synthesis of transdisciplinary knowledge. This contributes toward significant advances in our society.

In summation regarding the research, we discussed a societal impact. We also discussed how creativity can be applied in the global sphere for innovation to disseminate.

The applied result from clinical applications discussed within individuals includes individual differences. Clinical applications were discussed from medicine, neurology, psychology, music therapy, and art therapy. In sum, creativity may have special meaning to each individual. Furthermore, something may be deemed unique or creative by the individual rather than by society. Furthermore, there may be a shift where individual needs and reflections have even greater importance.

Our consensus was that science and art are intertwined and they both need each other for societal advancement.

Creativity is a choice and creativity needs to be fun.

It is also important to note that the individual and societal perspectives are also two complementary and interrelated coexisting constructs. The individual may be influenced by society and their environment, but may also influence their environment and society.

Furthermore, each individual possesses strengths that may play a key role in character development throughout the lifespan. Development perpetuates throughout one's own timeframe. Confidence may play a key role in engagement and flow. We need to believe in ourselves!

Creativity and critical thinking are higher order thinking. Furthermore, creativity is an attribute that we all can experience. Diversity enhances this process. The power of creativity is accessible to all, given one wants and chooses to be creative. The creative process is highly important, in addition to creative products.

We will also discuss implications for future uses through transdisciplinary collaboration that may benefit society in our next chapter.

10.7 Student Reflections…

10.7.1 Creativity Conversation Reflection

Jill Francis

After everyone sat down with the first question "In your own words define creativity" was asked. (The videotape did not work on this question). Going around the table in a round robin fashion, each person gave their definition of creativity. The conversation started with the idea that creativity is something that is used in situations in order to solve problems. The conversation continued and expanded into the idea that each person has somewhat of a creative "tool box". For each person, the toolbox attains a set of skills that have been developed throughout his/her lifetime. The skills in the tool box are what we use when it comes to being creative. It was also mentioned how every aspect of creativity we exert, is something we have seen before or a combination of things we have seen before. There was also more conversation about skill building and how education up to the undergraduate level provides skill building and develops skills to the point to where they can be used creatively out in the world.

Stories were shared about experiences of flow in times of work or play or just "being in the zone." Examples of flow that were mentioned were experiences during activities including playing basketball and also surfing. A musical therapist shared a sad but touching story of when she was working and caring for a small baby who was very ill and ended up passing on. During the baby's life, she shared how she played music and sang for a small baby during time of discomfort. She said a particular type of music seemed to really resonate with the baby in a positive way and acted as a source of relief. There was an agreement that there could be more support and funding for creativity in both areas of art and science. It was also discussed how creativity is important to teach so that it can be continued to be used to solve problems in the future. Around this point of the conversation, time had run out on the tapes, and the conversation ended.

Overall, it was a very insightful experience. It was very interesting to help facilitate and learn from a conversation with such experienced professionals.

10.7.2 Reflection

Segun Osinusi

It was wonderful to gain such new and exciting insights into questions that everybody has but rarely discusses. To hear the arguments from both sides, from people from such differing walks of life was truly eye opening. It was fascinating to hear others opinions on the role and implementation of creativity in many different roles and the societal implications that come along with it.

I thought it was very interesting to note how each individual thought of creativity and how their current occupation had impacted and framed that idea. The debate over whether or not artists are more creative than scientists can likely never be answered as artists are usually required by definition to be creative whereas scientists follow stricter rules and must find creative ways to navigate through them. Even though the fields differ so drastically, a lot of the same strategies are used to come up with the inspiration and implementation of ideas: taking a step back, relaxing, focusing on something else, being clear on your goals, allowing your mind to roam freely.

It was also interesting to delve deeper into some of the unspoken aspects of creativity such as the role of squelchers and encouragers, the fear of failure, and age. While external validation can bring merit to the creative process, the process in and of itself is already an impressive feat and shouldn't be discounted. This process can be defined in myriad ways and isn't solely confined to any one aspect of life. Getting to the root of creativity will be no easy feat, but we're certainly on the right track as evidenced by people of various occupations and backgrounds coming to agreement on certain core values of creativity. I can only hope that further research and discussion will help spread the word.

Chapter 11
Transdisciplinary and *Future Directions* from Our Conversation Among the Cultures in Science and Art…

Christine Charyton, Ted M. Clark, Alejandra Ferrer, Anne Harding, Herbert Newton, Robert J. Perry, Jill Francis and Segun Osiniusi

C. Charyton (✉)
Department of Neurology, The Ohio State University Wexner Medical Center, Columbus, OH, USA
e-mail: charyton.1@osu.edu; Christine.charyton@osumc.edu

T.M. Clark
Departments of Chemistry and Biochemistry, Research Experiences to Enhance Learning (REEL), The Ohio State University, Columbus, OH, USA
e-mail: tedmclark@gmail.com

A. Ferrer
Nationwide Children's Hospital, Columbus, OH, USA
e-mail: Alejandra.Ferrer@nationwidechildrens.org

A. Harding
The James, Ohio State University Wexner Medical Center, James*Care* Survivorship, Columbus, OH, USA
e-mail: Anne.Harding@osumc.edu

H. Newton
Department of Neurology, Neurosurgery, and Oncology, The Ohio State University Wexner Medical Center and James Cancer Hospital, Columbus, OH, USA
e-mail: herbert.newton@osumc.edu

R.J. Perry
Department of Physics, The Ohio State University, Columbus, OH, USA
e-mail: perry.6@osu.edu

J. Francis
Logistics Business and Entrepreneurship, Fisher College of Business, Columbus, OH, USA

S. Osiniusi
Department of Psychology, Columbus, OH, USA

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11.1 Neurobiology of Creativity and Music—Future Directions

Herbert Newton

Although there have been excellent advances in the field of the neurobiology of creativity over the past few decades, further progress is needed. The model proposed by Dr. Flaherty is the most advanced synthesis of the available data thus far, but is only a starting point toward our complete understanding of this aspect of human cognitive neuroscience. The model takes into account the activity of the frontal lobe and the temporal lobe, down the *X*-axis, along a continuum of normal and abnormal function. Creativity seems to be maximized with normal frontal lobe function, and mild-to-moderate dysfunction of the temporal lobes (i.e., before entering into the realm of mania and psychosis). Along the *Y*-axis, the level of dopaminergic activity is plotted—another very important neurobiological component in the process of creativity. For creative drive to be maximized, dopaminergic activity must be in the moderate to high range. The model would be more accurate and helpful if it had 3 dimensions, so that frontal lobe function and temporal lobe function could be plotted separately and behave independently. Other neurocognitive subsystems also need to be represented in the model for it to be more robust and accurate, including the activity of specific regions of the frontal lobes (orbitofrontal, dorsolateral, medial frontal) and temporal lobes (lateral, medial). In addition, it would be helpful to be able to plot the level of circulating catecholamines and amount of cortical arousal—thereby estimating the size and connectivity of available neural networks—which are also very important in the process of creativity. Further advances in this field will take collaboration from researchers in the fields of Cognitive Neuroscience, Cognitive Neurology, Psychology, and Brain Imaging. In particular, more studies of creativity while performing functional MRI scans and diffusion tensor imaging MR scans will hopefully fine-tune our ability to pinpoint the regions of the brain involved in various aspects of creative activities, as well as the neural networks and connections that are activated in these endeavors.

The neurobiology of music has made tremendous advances over the past 20 years, especially with the explosion of new, noninvasive methods to image the brain and access ongoing, localized brain activity (e.g., PET, fMRI). With those advances have come several neurobiological models of music processing; the most complete and sophisticated model is from Koelsch and Siebel. This model is able to follow the musical input signal as it enters the auditory apparatus and auditory pathways in the brain, where it undergoes a very complex and complete analysis of the features of the musical signal, including basic aspects such as pitch height, pitch chroma, timbre, intensity, and roughness, as well as more advanced aspects including melody, harmony, chords, time intervals, rhythm, and meter. In addition, this model is able to account for the emotional aspects of music (e.g., joy, happiness, rapture), and the various ways our bodies can react to music, such as autonomic responses (e.g., goose bumps). Although this model is very good, there are still many unanswered questions about musical processing, and the neural networks that underlie the many different aspects of that processing.

The techniques for imaging the brain during music processing need to be advanced, so that we can obtain more detail during PET scans, fMRI, and MEG, about the specific subcortical regions, neural networks, and connections involved. Another critical issue that has to be improved is the lack of standardization of techniques, parameters, and conditions that are used in music processing research. Every small difference in technique, conditions, and research parameters leads to subtle variations in the activation patterns and neuroanatomical substrates that are recorded in the data. Important questions still remain about many aspects of music processing, including how the brain creates, categorizes, and stores musical gestalts, and which neural networks mediate this function.

How does the process of musical perception interact with the autonomic nervous system, hormonal systems, and immune system? How do the different musical processing compartments interact with each other, and how is this mediated in terms of neural networks and connections? How is the musical lexicon stored and analyzed, and how does it interact with the other compartments of music processing? Along with many more questions that need to be answered, some of which are contained in the Summary of Sect. 2.2.8. Further work by Cognitive Neuroscientists, Cognitive Neurologists, Psychologists, biological Musicologists, and Neuro-Imaging Specialists will be necessary to design and perform the studies that will eventually clarify all of these interesting and important aspects of the neurobiology of music.

11.2 Future Directions: Music Therapy

Alejandra Ferrer

The future for music therapy is a promising one. Through the past 60 years as an organized profession and formal field of study, music therapy has continuously worked toward achieving greater levels of respect and recognition from the medical community, developing a comprehensive research base that substantiates the work with various clinical populations, and has steadily expanded in regard to populations served and techniques and protocols used. While these efforts and achievements have not gone unnoticed, much work lies ahead.

One of the biggest challenges faced by the music therapy profession is its small size. Approximately 6,000 music therapists currently hold the music therapist-board certified credential in the United States (Certification Board for Music Therapists 2011). In comparison with other helping and rehabilitative professions such as nursing, physical therapy, and mental health counseling, significant growth is needed. A greater number of music therapists in the workforce would ensure increased access to services for those who need music therapy. Additionally, the presence of more music therapists across medical settings would assist in "normalizing" and "demystifying" the field, as more professional communities would become familiar and educated on the role and scope of practice of the music therapy professional. This would also assist in the music therapist becoming an essential, indispensible member of the interdisciplinary treatment team, rather than a "uniqueness" or "privilege."

As important as growing in size, is diversifying the workforce. Currently, the majority of music therapists are Caucasian females, which does not accurately represent or reflect the individuals served by music therapy. It is logical to assume that unique clinical situations may arise where a therapist of the same gender, ethnicity, or religious background would be of preference for the client. A more diverse therapist workforce including a greater number of males, ethnic minorities, therapists from different religious backgrounds as well as therapists of different sexual orientation and gender identity could ameliorate this challenge.

Continuous efforts to enhance the quality of the music therapy research are also a major goal for the profession. Increasing the amount of studies per clinical population, technique or protocol used, producing studies with clean and transparent methodologies, and engaging in large-scale studies with a robust number of subjects will augment the validity of our results as well as elevate the status of music therapy among professional communities. Research done in collaboration with professionals from related disciplines who may have greater research knowledge and experience including those from medicine, psychology, and neuroscience will not only benefit the individual studies, but may perhaps "open the door" to clinical populations and problems that have not been tapped into by music therapists. These collaborations will increase our knowledge base, and at the same time, integrate us further into the medical community. Collaborations may also help to diminish any perceived researcher bias, as the music therapist, along with the non-music therapy professional, is viewing the same problem, treatment, and outcome from a different lens.

In summary, the poignant idiom "the world is your oyster," beautifully depicts the future of music therapy. Through the daily efforts of each and every member of the music therapy community and the support of professionals from related disciplines, the field of music therapy will remain ever evolving, continuously identifying new ways to promote and improve the lives of those who need it most.

11.3 Future Directions: The Future of the Field of Art Therapy

Anne Harding

There is much ground-breaking therapy on the horizon in the field of neuroscience and art therapy. I believe we will see rapid changes in the next 10 years as we are now able to map changes in the brain related, not only to creativity, but also in responses to trauma such as early childhood violence. New research in fields such as neuroplasticity has great potential in the way it can be applied to the field of art therapy providing substantial validation to the changes that many art therapists know occur, for which we have not been able to provide substantial evidence to back up our claims. Because of its highly subjective nature, the benefits of art therapy have been largely anecdotal for many years. As new ways of recording changes in the brain advance, we can now document what is occurring from both a phenomenological and a scientific perspective. Cross-disciplinary approaches such as those mentioned in my chapter seem to be the wave of the future in art therapy. As the conversation between authors revealed, more conversation and more collaboration are needed to effectively understand the differences and to combine the areas of science and art into something mutually advantageous. Perhaps we are not as far apart as it may seem.

Another area of rapid advancement in the field of art therapy is seen in technological changes. Many courses are now offered online to art therapy practitioners and to those seeking therapy. A growing network of idea-sharing both nationally and internationally is allowing the field to explore new concepts and combine expertise. There are also now practising online art therapists. Obviously, this opens the door to a whole new realm of ethical dilemmas, which are now being addressed by the governing boards of therapists, just as it does in other psychological therapeutic and counseling fields. There are currently thousands upon thousands of sites offering therapeutic art. This may include creating digital or hand-rendered therapeutic images or pieces such as mandalas, soul collages, art cards, paintings of every description, animal totems, art journaling, altered books, group art, and much more. Some may be offered as art therapy, others as therapeutic art without the advantage of an art therapist to moderate the process and results. As technology changes, it will truly take creative minds within our field of study to craft a practice that continues to uphold best practice and ethical guidelines and continues to provide personalized care. Finally, just as art, whether in therapy or not, has historically been both a solitary and a community practice for individuals to creatively make sense of the world, neither science nor technology can take place of the interaction between humans and their artistic toolbox; however, that toolbox and its contents is defined. I found the topics in the conversation on science, innovation, and creativity to be thought-provoking and warranting further discussion.

11.4 Future Directions: Physics

Robert J. Perry

Having to think about the role of creativity in my research and discussing it with other faculty have drastically increased my interest in the subject, but its primary impact on my work will probably be in the classroom. I have long thought about the difficulty many of our graduate students have when transitioning from classroom work to research. I think a great deal of this difficulty stems from the need to be far more creative when identifying good research problems and attacking them.

We simply do not focus on the creative nature of the original work when we teach physics or, when we do, we simply give historical accounts that provide little or no discussion of how creativity entered. Students are probably left with the impression that brilliant ideas are simply born fully formed from the minds of brilliant scientists. All of us love stories with a hero, accounts that seem complete when we see a sketch of one scientist's activity. Even in the cases where there is a Newton or an Einstein at the focus, their creative bursts were not born in a vacuum and did not emerge fully developed.

When thinking about how to bring more discussion of creativity into the classroom, I find it incredibly useful to think of creativity quite broadly. Although in appearance, the artist's creativity seems quite different from the scientist's, I have come to believe that the similarities are more important than the differences. Creativity requires the sort of risk-taking we like to think we encourage but which we seldom reward in the classroom. Early failure can be more important than success when seeking a totally new perspective on a scientific problem.

Mastery of established techniques and widely held beliefs is important, just as an artist who creates a new type of music or art must often rely on established work. But the habit of constantly exploring, of trying new ideas and seeking new approaches, is not built from imitative forms of learning. I hope to bring some of these insights to bear on my teaching and encourage students to go beyond looking up the correct equation. For example, in many cases, we can expound some of the basic techniques that lead to new equations and then give the students a chance to invent new equations on their own. By considering the qualitative features required of a solution and using common simplifying ideas (e.g., first try a linear equation), students can be led through the development of some basic fundamental equations in physics and encouraged to start reinventing solutions for themselves. I have found it remarkable that many of the best minds in theoretical physics have a habit of trying to figure everything out for themselves. They glance through an article or book to get sense of the problem, perhaps a hint of how it was solved, but they then attack it on their own and return to the source primarily to compare their solution with what is accepted. Not surprisingly, by doing this for years, they sometimes come up with a new idea or approach to old problems and they ideally prepare themselves for that rare opportunity to advance a whole field by being the first to come up with a breakthrough.

11.5 Future Directions for Promoting Creativity in Chemical Education

Ted M. Clark

Although not articulated in this way, promoting student creativity is an objective common to current reform efforts in science education. For example, the move toward inquiry-based laboratory experiments that include greater decision-making offers an opportunity for innovative problem solving in a way that traditional expository laboratory experiments cannot. The inclusion of authentic in-class research experiences in undergraduate courses, in projects such as REEL and others like it, holds even greater promise for promoting creative problem solving as students have a voice in generating and investigating a research question that may have value to the broader scientific community. In other words, participating students learn more about the discipline's current scientific paradigm by engaging in problem solving within it. While such experiences have long been offered for upper-level students, efforts to place them in introductory courses represent a reappraisal of the requisite knowledge and skills one must have to function in the laboratory vis-à-vis the application of these skills in an independent, creative manner.

Authentic research programs are often complex and multidimensional, and a well-designed in-class project provides many students with an opportunity for ownership of a research question that also contributes to a larger, macroscopic research program. The challenge educators face crafting such overarching laboratory experiences requires considerable creative problem solving, and typically new ideas are tried, revised, improved, etc., with much greater frequency in these settings than in traditional laboratory courses. A traditional laboratory experiment that "works" may stay in the curriculum for decades; the lifetime for an in-class research experience is far less. In a noteworthy development, some chemical educators seeking to improve their in-class research experiences have begun including laboratory tasks that explicitly call for student creativity and artistic expression. A leading example is the evolution of an in-class research project at The Ohio State University (OSU) involving investigation of inorganic pigments.

The chemistry of inorganic pigments has been investigated at many universities throughout Ohio as part of the REEL program, with thousands of students synthesizing and characterizing pigments to systematically manipulate properties, such as color, while replacing harmful elements traditionally used in their manufacture with benign ones. This project, under the leadership of Dr. Rebecca Ricciardo, has been expanded to now include the synthesis, characterization, and *use* of inorganic pigments. Having prepared different-colored pigments as part of their research project, student groups then construct egg tempera paintings in laboratory. When implemented at a large institution such as OSU, this results in hundreds of paintings in a semester. These paintings are then shared and disseminated in various ways, such as through social media and at research poster sessions. The top works are then selected for inclusion at local art gallery events that are paired with demonstrations communicating the "science" behind pigment synthesis. This is a novel integrated experience, as the science student becomes an artist and the viewer of art learns the science of color and pigments.

This re–imagined pigment project allows students to benefit being engaged in an artistic, creative process. In addition, beyond gaining a greater appreciation of why pigments are different colors, they have worked to generate new scientific knowledge in an area that also supports content learning in the course. Pedagogically, both at the K-12 level and in higher education, arts *integration* has been used as an approach to support teaching and learning. The focused activity described here is perhaps better described as art *inclusion,* as it represents a single specific experience with the clear objective of students being creative and enjoying accompanying benefits such as a sense of freedom, self-expression, stress relief, and community.

An interesting question is how students in an introductory science course perceive the inclusion of art in a laboratory experiment. These students are quite pragmatic and value the duration of a laboratory (how long does it take?), how it is evaluated (what needs to be turned in?), and how it supports their learning of course content (will I score better on the test?). In-laboratory painting activities, at one level, run counter to these criteria since they makes the laboratory longer, are not scored, and do not provide content knowledge for the examination. How has such a diversion been received? Initial results are remarkably positive, with three-quarters of the students identifying painting as an enjoyable activity and 80 % believing the painting portion of the laboratory should be retained. With about 40 % of students agreeing that painting with pigments changed their view of chemistry and its applications in everyday life, it is clear that arts inclusion has potential to supplement both traditional laboratory instruction and in-class research experiences. Further work in this area, and accompanying examination of what it means for fostering student creativity, is an exciting future direction for chemical education research.

11.6 Future Directions: Science and Art

Christine Charyton

The integration of science and art with transdisciplinary science is only beginning. If we are talking about synergistic fields such as neuropsychiatry, neurobiology, or bioengineering, the integration and synthesis of these fields are newly established, yet are continuing to blossom.

With technological advances, the integration of science and art is becoming more and more salient. Science and art complement each other. Technology is a tool that can facilitate their integration as well as their application to reach more users.

My students (and also my innovative family) have inspired me by our conversations to select and purchase an electric vehicle. My GM Volt gets over 250+ mileage on a tank of gas in the spring. I occasionally fill with fuel on no sooner than a monthly basis even in the winter, when the vehicle uses more electric. The gas tank is no more than 9 gallons. Creativity is the true vehicle and foundation for innovation. Pretty soon, we will be seeing more vehicles that run on electric and alternative fuels. Electric, solar, and other alternative energy sources are the wave of our near future.

In our conversations during the classroom, we discussed solar energy and additional technological advances that already exist such as the solar toothbrush.

Some inventions may be more useful than others. Some inventions reach more people than others. Most of all, some inventions may take time not only to advance, but also to catch on. This is true for engineering design in addition to scientific and artistic discovery, problem solving, and problem finding.

Conceptually speaking, more and more creative advances will continue to further develop and touch more and more aspects of our lives as well as reaching more individuals. However, we must never forget our truly human element that breathes creativity. Technology is a tool that is useful for humans; however, we control, manage, and use the technology at our discretion. Humans are more creative than technology. We create technology. Furthermore, we all can be creative if we choose to be creative. Creativity is an inherent human quality that makes each of us special. Just as each person is unique in his or her own manner.

Inspiration is a light that shines from each of us. If we want to be creative and use creativity, we can. Creativity should also benefit humankind and help others. This perspective strongly opposes the highly published "dark side" of creativity. Creativity is light that shines and is a source of good intended to benefit humankind. We can inspire and be inspired and use creativity in our lives if we choose to use our creativity.

May the light of creativity continue to shine with you on your journey…

11.7 Student Reflections on Future Directions…

11.7.1 Future Directions

Jill Francis

After graduating this spring with a Bachelor of Science degree in business administration, I am now currently searching for a job in the supply chain and logistics field. I am seeking a full-time job with companies offering positions in which the requirements are met by my educational background. I am also planning on working on projects in my free time. These projects include updating a blog with my pictures and writings, and I also have in mind a video project that I would like to start in the near future as well.

My initial interest in creativity spurred from course elective from the entrepreneurship minor I pursued at Ohio State University. I chose this minor because I would eventually like to start my own business. The business would include promotional items such as T-shirts and other athletic wear. Similar to Nike, the items would spread positive motivating messages. As of right now, my future directions are very broad, but the subject of creativity has taught me how to brainstorm ideas constructively and overcome squelching to use and apply skills that I have learned toward constructive outlets.

11.8 Future Directions

Segun Osiniusi

As far as future direction, I think it would be incredible to see most every problem solved with a cross-disciplinary approach. I feel as though that is the only way we can make truly substantial progress. If people are allowed to pursue their passions to the greatest of their abilities, I see no reason why any field would remain stagnant. People give their best performance when they are intrinsically motivated to do so. I believe that fostering these innate qualities in a given individual will allow them the means to flourish and be of much more benefit to society.

This is certainly a conversation that must be held on a more frequent basis on a larger stage. Too few people give enough thought to the role of creativity and passion in any given field. We have coined the term "innovation" and have since only applied it to technological advancement, failing to realize that the source of this innovation is the seed of creativity. We cut music and arts programs, force-feed children rote mathematics and science classes, and expect them to find joy in school. We have cut recess and sports programs, forcing more children to focus more solely on academics and wonder why the United States is falling farther behind in education and losing its position as the economic leader of the world. People are no longer substantially motivated. We have told people for years to stop dreaming, to get their heads out of the clouds. Yet, the clouds are the very place from which we draw inspiration. This fuzzy urges to pursue a natural idea, this inclination to better an existing system, this drive to bring something existing in the mind into reality, this very thing we stifle on a daily basis, this is the source of life, of joy.

Merely, implementing a structure of test/reward is not substantial enough to get the very best out of people. Human nature is to do the bare minimum to get by when approached like that. That is exactly what efficiency is, spending just enough energy to still produce comparable results. In order to give 100 % and throw caution to the wind, one needs to be internally motivated via the pursuit of happiness. Creativity, in a nutshell, is that pursuit.

Reference

Certification Board for Music Therapists. (2011). The Certification Board for Music Therapists. Retrieved June 29, 2014, from http://cbmt.org/.

Glossary

Accleration The rate of change of velocity per unit time, including both the magnitude and direction of this change

Aesthetic Value Between 0 and 2 and has often been interpreted as pink noise being more aesthetically pleasing; however, we suggest that Brown noise may be more aesthetically pleasing

Alzheimer's disease The most common form of dementia characterized by memory loss, a decline in behavior and thinking abilities, confusion, irritability, mood swings, and aggression

American Music Therapy Association The governing body for the profession of music therapy in the United States

Amusia A neurological condition that is either acquired or congenital, and results in the inability to process or enjoy music

Aphasia A communication disorder that affects receptive and expressive language skills

Apraxia The inability to execute learned purposeful movements

Art therapy Art therapy is a profession which provides clients the opportunity to identify, explore and express their feelings through the creative process using various media. The artwork created can be used as a tool between client and art therapist to explore psychological issues, improve cognitive and emotional function, to enhance self-awareness and self-esteem, to develop coping skills, and reduce anxiety or generally promote a sense of well-being. Art therapy is used in a variety of settings including educational, social, developmental, psychological, rehabilitation, mental health and medical settings and others. Art therapy is facilitated by a trained art therapist and can be facilitated in a group setting or individually. A master's degree is required to practice art therapy. For further information individuals may contact the American Art Therapy Association or the Art Therapy Credentials Board, Inc.

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Artist Earning income in an artistic endeavor such as painting, dancing, writing, cinematography, music or poetry. Can be as little income as selling one painting

Brown noise More regular and predictable than white or pink noise

Brownian Motion Robert Brown observed particles of pollen in a microscope decomposing in the aqueous solution to be displaying an irregular motion

Calculus The branch of mathematics dealing with the derivatives and integrals of functions

Case Study An illustration of conceptualization and thought processes of an individual or culture to understand the dynamics and rationale of the topic being studied

CEDA Creative Engineering Design Assessment. Tool to assess engineering creativity specific to engineering design that incorporates convergent and divergent thinking as well as originality and usefulness

Certification Board for Music Therapists a national board that certifies music therapists in the United States following the successful completion of the board certification exam.

Cognitive Behavioral Therapy Identification of thoughts and feelings for behavior

Constraint Satisfaction Working within constraints to create a design

Convergent Thinking Generating a solution to a problem

Convergent Validity Constructs that are a like or similar to the construct being compared

Cossack Ukrainian warriors that would protect Ukraine from invaders such as the Russians, the Poles and the Mongols. The Ukrainian culture has dancing that is reflective of these great warriors

Creative Music Therapy Approach See Nordoff-Robbins Music Therapy

Creativity Creative ideas or activities are defined as a concept or formulation that is both novel and useful in a particular social setting. Alternatively, it can be defined as the ability to understand, develop, and express in a systematic fashion novel relationships

For purposes Chap. 4, creativity refers to be act of being creative, or producing a new or original image, art object or artistic expression using imagination which can then be used to formulate a solution to a problem or enhance understanding of self or the world

Novelty, applicability and usefulness

Culture How the environment may play a role in creativity. The thought processes, history and activity that may have an influential role on the development of creativity

Diagnostic and Statistical Manual of Mental Disorders A manual published by the American Psychiatric Association that offers standard classification of mental disorders

Dialectical Behavior Therapy A type of cognitive-behavioral therapy aimed at helping people change ineffective behavior patterns such as self-harm and suicidal thinking by learning to identify triggers and self-regulate

Discriminant Validity Constructs different from the construct being compared

Divergent Thinking Generating multiple solutions to a problem

E. Thayer Gaston A pioneer for the field of music therapy in the United States

Electromagnetism The branch of physics dealing with the interaction of charged particles and currents through electric and magnetic fields

Electron The lightest negatively charged fundamental particle

Emblem Symbol to represent a country with significance and meaning. E.g. USA Eagle, Ukrainian Tryzup

Empowerment For the purposes of this chapter, empowerment is the development of interpersonal and intrapersonal skills and strengths which can lead to a sense of mastery or provide a sense of more control over one's well-being

Energy A fundamental property of all particles and fields that is determined by their ability to do work

Engineer Stemming from the Latin Ingeniatorum meaning "ingenuous" with "gen" referring to the act of creation or "Genesis." Creativity, create and engineer stem from the act of creation

Engineering Creativity Originality, usefulness and functionality specific to engineering

Existential Related to the state of being, or existence. Someone who is dealing with a life-threatening disease may feel the need to take a closer look at existential issues

Expository Verification laboratory format, A laboratory instructional style where students complete a given procedure, often provided in a "recipe" format, to deduce from their data a predetermined outcome

Flexibility Categories of responses

Flourish For purposes of this chapter, to have a sense of well-being and optimism through positive emotions and relationships, a sense of resiliency and meaning and purpose in life

Flow A concept coined by Csikzentmihalyi, M. related to being at one with something or absorbed by the activity to the extent of losing a sense of time. For more information see Csikzentmihalyi (1990). *Flow: The psychology of optimal experience*. New York: Harper

Fluency Number of responses

Fractal Smaller, nested copies of the whole object

Frequency The rate at which something repeats

Functional Creativity A type of creativity specific to engineering. Making designs that can work

Gnosia The inability to recognize and identify objects or persons

Gyri of Heschl (HG) Located on the dorsal surface of the superior temporal convolutions, final destination for auditory pathway fibers. Primary auditory cortex is contained within the medial portion of HG, while secondary auditory cortex is in the lateral portion of HG

Holodomor One of the worse genocides of Stalin on Ukrainians where Stalin starved approximately 10 million Ukrainian men, women and children to death. People engaged in cannibalism in effort to survive. Ukrainians starved and froze to death despite their fertile land since Stalin demanded crops to resell them to Europe

Improvisation Flowing of notes and ideas to create their own opportunity to express their own individual creativity. May be most commonly expressed through jazz improvisation

Innovation The vehicle in which creativity can be expressed. The application of creativity having a broader impact in society

Instructional scaffolding Specialized instructional supports to facilitate learning when students are first introduced to a new subject

Lobar Theory Suggests that creativity is mediated by interactions between the temporal and frontal lobes, along with activity from the limbic system and catecholamine neurotransmitter systems

Maidan Square in Kyiv were peaceful demonstrators protested Yanukovych's decision to go with Moscow as opposed to the European Union like many Ukrainians desired. Over 100 Ukrainians were murdered, shot with rubber and silver bullets. Men, women and children died peacefully protesting. Artists, poets, musicians, engineers and students were brutally murdered. Over 500 people disappeared (were tortured, brutally murdered, and some were brutally tortured and few were let go without being murdered). This protest was known as the Revolution of Dignity

Meaning-making Meaning-making is a way of exploring existential issues to explore and develop a better understanding of one's existence. Using the creative process can help with meaning-making, thus helping individuals to develop life-affirming meaning to their existence

Measurement Observer ratings, self-report and objective measures may attempt to assess and measure improvisation ability, higher order thinking, and improvisation achievement

Mechanics The branch of physics dealing with the motion of objects and the forces that change the speed and/or the direction of this motion

Melody The linear succession of pitches or notes (i.e.., the "horizontal" aspect of music) that the listener perceives as a single musical phrase that is the centerpiece of the song. The core of a given melody is usually created with the use of chord progressions, scales, or modes

Metaphor For purposes of this chapter, the use of a word or a theme that is used to represent something else as a way to address something indirectly. In art therapy, metaphor is often used as a "back door" approach to address difficult issues. It can also simply be an expressive way to illustrate and explore mental, emotional or physical states of being

Momentum A fundamental property of all particles and fields that relates to their quantity of motion. For a particle, this is given by its mass times its velocity

Mozart Effect The possible effect of early exposure to music on cognitive abilities and IQ. It was first noted after an experiment that used a Mozart sonata

Music Therapy The use of music-based interventions to help individuals achieve goals of a cognitive, physical, social, and emotional nature

Music Music is sound that is organized according to principles of pitch, rhythm, and harmony, with musical timbres that allow for the differentiation between musical sound sources and musical instruments. Furthermore, music can be conceived of as individual abilities to process and respond to sonic patterns that are constituted by complex pitch and rhythmic structures

Musical Creativity Originality specific to music

Musical Lexicon The neural representations of songs, melodies, and musical phrases that are familiar and can be easily recognized or imagined in our minds. It is considered to be a music specific memory system

Musical Syntax The degree of expectation that a listener has about the musical notes that will fit properly within a specific musical reference, in relation to the musical key, melody, harmony, and chord structure. It is considered a relational "pitch framework" used to analyze the content of music, similar to syntax in language

National Association for Music Therapy The first professional organization representing music therapists in the United States

National Association for Schools of Music The national accrediting agency for music and music-related disciplines in the United States

Nature of Science The key principles and ideas that describe science as a way of knowing, as well as the characteristics of scientific knowledge

Neural Connectivity The degree of interactions between neurons within the cerebral cortex, as well as between different lobes and nodes of the brain, are very important in mediating the ability to be creative. Increased size and connectivity of neural networks is critical to being more creative

Neurobiological Model Dopaminergic activity along the Y-axis (low to high), Lobar Activity along the X-axis. In the middle of the X-axis is normal frontal and temporal lobe activity. As you pass from the middle of the axes towards zero, you reduce frontal lobe activity and pass into Creative Block further frontal reduction leads to depression and/or abulia. Moving from the middle of the axes towards infinity you pass into an area of reduced temporal lobe activity and Creative Drive further temporal reduction leads to mania and psychosis

Neutrino A fundamental particle that interacts weakly. It can easily pass through the entire planet with no change in its motion

Neutron A subatomic constituent of the nucleus with no electric charge that interacts strongly. It is composed of quarks and gluons

Nordoff-Robbins Music Therapy A music therapy approach developed by Paul Nordoff and Clive Robbins rooted in the belief that everyone can respond to music, no matter the level of disability

Normal science (Kuhn model) Thomas Kuhn's concept describing the regular work of scientists as operating within a settled paradigm, or explanatory framework, and acting as "puzzle-solvers"

Originality Novelty. A new idea or design

Paradigm A typical example or an underlying point of view

Particle An indivisible constituent of matter

Pink noise Less predictable than Brown noise and more predictable than white noise

Pitch Contour Refers to the relative change in pitch over time of a primary sequence of notes in a piece of music (i.e., the "ups" and "downs" in the song). It can also be considered as the "envelope" of pitches around the core notes of the music

Pitch The perceived sensation of the frequency of a given note in a piece of music, with different notes being relatively higher or lower in pitch to one another. Higher frequencies are associated with faster vibrations, while lower frequencies are associated with lower frequencies

Planum Temporale (PT) Located just behind the HG in the dorsal temporal lobe; functions as an auditory association area. Very important for musical processing (especially pitch)

Polymath The expression of creativity in more than one field, discipline or domain. Exceptionality in multiple areas. Case studies of Ukrainians excelling in more than one discipline (see chapter)

Positive psychology A term coined by Martin E. Seligman (see chapter) referring to a theory of well-being which incorporates positive emotion, engagement or a sense of flow and having a meaningful purpose in life

Problem Finding Foreseeing other potential problems that could potentially occur in order to solve them

Problem Solving Solving a problem

Proton A subatomic constituent of the nucleus with positive charge that interacts strongly. It is composed of quarks and gluons

Quark A fundamental particle that interacts strongly

Reliability Psychometric consistency

Research Experience to Enhance Learning (REEL) program A program sponsored by the National Science Foundation from 2006–2011 that designed and implemented in-class research experiences in introductory Chemistry course at higher education institutions in Ohio

Savoring To enjoy or appreciate something past or present in an unhurried manner. For instance, someone might savor the sights, sounds and smells of the ocean while on vacation at a beach destination. Or someone might savor the memories of jam-making with Grandmother while viewing a photograph or drawing or painting a picture of a past event, or actually smelling or tasting strawberries

Science Not limited to natural or biological, but includes social science, invention, mathematics, application and engineering

STEM Science, technology, engineering and mathematics. Methods to increase recruitment and retention in these areas include adding creativity and innovation as experiential learning activities

Timbre Also known as tone color or tone quality, it is the unique characteristics of a given note or sound, and allows for the ability to perceive the differences between different voices and instruments. It includes sonic qualities such as harmonics, spectral envelope, time envelope, brightness, and warmth

Trypillians Ancient Ukrainians dating back to 5400B.C. The first white native habitants that were the first to bake bread and melt metal. They lived in Trypillia which was south of Kyiv in Ukraine

Ukraine The country meaning borderland and the boundary between the Asiatic East and Western Europe. In the 12th Century and the 19th Century Ukraine was the Kozack or Cossack State to protect Christianity and the boundary with the Asiatic region. Cossacks protected Ukraine from Mongols and other invaders including the Tartars. Ukraine adopted the Tryzup as their emblem and the blue and yellow flag. Ukraine has been known to be the breadbasket of Europe as well as the former Soviet Union. Despite Ukraine being the breadbasket with rich black soil, 10 million Ukrainian were starved to death under Stalin's dictatorship. Many speculate that Putin is even worse than Stalin. Ukrainian bishops from Kyivian Orthodox and Byzantine Catholic churches have stated that Putin in under the influence of Satan

Ukrainians 45 million people in Ukraine and 15 million in outside countries that identify themselves as originating from and having their ethnic identification in Ukraine

Usefulness Practicality for potential or current uses

Validity Application of measuring what the construct measure is supposed to measure

Vector A mathematical object with magnitude and direction

Velocity The speed and direction of motion

Wavelength The distance between successive peaks of a wave

White noise Least predictable and least aesthetically pleasing

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