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Abstract

Research in the new sciences (quantum physics in particular) has been yielding principles for how the physical world operates in subatomic realms. These ideas are surprisingly similar to the foundational principles of so-called "constructivist" learning theories that have been emerging in education. Integrating scientific and educational theory offers fresh insights as well as candidates to replace the computer as a metaphorical guide for teaching and learning in the 21st century. In particular, metaphors such as "holographic thinking" and "classrooms as vast porridges of being" are poised to replace "information processing" and "classroom management" as the hallmarks of educational practice. In this paper, I outline five key principles of quantum science with particular relevance to constructivism. With the help of new scientists, groundbreaking musicians, and interdisciplinary scholars, I then demonstrate how these principles are, in turn, reflected during improvisation that occurs among players, conductor, composer, and audience in a musical ensemble. Jazz is an especially apt model for applying the principles of quantum consciousness to teaching and learning in a successful classroom. The end result is a set of profound implications for the role of teachers as jazz band leaders and learners as performers and active interpreters in an improvisational classroom.

Keywords: *quantum science, constructivism, improvisation, education, music*

Improvisation and the Quantum Classroom:
Musical and Scientific Metaphors to Guide Teaching and Learning in the 21st Century

It may sound too theoretical, but it is a fact that how we educate our kids depends on the prevalent worldview of the educational establishment. And right now, that worldview is scientific materialism—the idea that everything is reducible to matter and its interactions. Corollary to this view is the Newtonian idea that we are mechanical machines. Accordingly, for the past 35-40 years, … we have developed an educational system that treats human beings as machines.
Amit Goswami (2016)
Theoretical Quantum Physicist

Helping fuel a cognitive revolution in psychology, the computer became the 20th century's consensus metaphor for learning and the human brain.The use of metaphors to identify a theoretical paradigm is not new. The clock served as a 17th century symbol that helped foster and reflect the development of a Materialist (often called Modernist) worldview that influenced science and education for hundreds of years. Although both clock and computer have been valuable assets to researchers and theorists, mainstream education's infatuation with such machines has eclipsed other exciting – perhaps even inevitable – ways of looking at intellectual abilities and social dynamics associated with teaching and learning. In particular, ideas from post-materialist, post-modern, or what Goswami (2016, 2017) also calls *transmodern* physics are vying to replace the computer as a metaphorical guide in the field of learning theory. Principles emanating from modern physics are, in turn, reflected in the relationship among players, conductor, composer, and audience in properly functioning jazz ensembles and nonconventional orchestral arrangements. Taken together, modern science and musical improvisation suggest implications for the role of teachers and learners in a "quantum classroom."

Materialist Metaphors

From a materialistic perspective, to understand the whole of something, one must break an object or situation into its constituent parts. The computer lends itself to such reductionist thinking, offering glimpses into the "black box" of cognition. Since the middle of the 20th century, prevailing theories about human thinking have often shared language with technology. Consider phrases such as short-term working memory, long-term storage, and so-called "artificial" intelligence. Cognitive scientists often talk about the computability of a theoretical model based on the assumption that running a "computable" program will resemble the human behavior a theory is supposed to describe. One educational psychologist (Reynolds, 2005) summarizes the adoption of the computer as a metaphor for thinking this way:

> Not only was the computer a means for testing theories, but it was considered a metaphor for human mind. Computers process data by representing it numerically and performing operations, which transform it. People were thought to be similar

> symbol-processing entities. Knowledge was redefined as information and processes performed on information (pg. 15).

Scientific materialism pervades education to this day, starting with the belief that a desirable truth exists in some objective state and that we will achieve certain results by scrutinizing elements of a problem and then employing prescribed procedures such as "data analysis" and "classroom management" until people and the environment fit our preconceived version of that reality. With mechanical efficiency, educational evaluators and school administrators assume the role of clockmaker or programmer, attempting to distinguish the most intricate components of cognition and curriculum in order to construct a world that is predictable and controllable. The computer has been an even more capable guide than the clock, helping investigators decide where to look and how to test for information processing abilities. The result is the same. Through a sort of theoretical sleight of hand, technology eventually became a mirror in the hands of researchers and practitioners, projecting and validating the very processes we think we have found in ourselves.

Post-Materialist Metaphors

This kind of circular reasoning often drives modern scientific thinking as well. In *The Structure of Scientific Revolutions*, Thomas Kuhn (1960) explains how paradigm shifts only happen when enough anomalies arise to force adherents to improvise by stepping outside of their own way of framing the world. For example, the earth began to shake in physics when scientists like Albert Einstein realized that Newton's laws were limited in their ability to explain certain incongruities, especially in the galactic and microscopic realms. From Einstein forward, thought experiments about certain phenomena have directed research, which evolved into theories of relativity and quantum mechanics that in turn began to explain those incongruities.[1] This has led to theoretical models that explain everything from the origins of the universe to subatomic elements of the physical world, often in very poetic terms (Leaderman, 2011).

Concurrent with this scientific revolution, a similar sea change was occurring in 20th century learning theory. As behaviorism and cognitivism dueled over the development of models for how the brain works – adopting metaphors such as switchboard and computer respectively to explain mental activity – an age-old theoretical perspective known as constructivism was lurking in the shadows and ushered in the 21st century. Grounded in the philosophical premise that reality is not objective, modern-day constructivists recognize learners primarily as meaning-makers as opposed to mere habit formers that can be trained or information

[1]A thorough discussion of relativity and quantum mechanics is beyond the scope of this paper. Suffice to say, the fact that both modern theories are viable while incompatible in many ways is itself one of the unique hallmarks of modern scientific thinking. In this paper, I will use the term "quantum" when referring to theories of quantum mechanics specifically, but also when referring to the "new physics" or "new science" in general, which incorporates the theory of relativity as well.

processing machines that can be programmed. According to a constructivist view, the role of prior knowledge and social negotiation in experiential situations is vital for new stimuli and experiences to evolve into a state of conceptual understanding. Furthermore, these variables are idiosyncratic to both individual differences and cultural context (Scheurman, 1998, Vygotsky, 1978). As we shall see, creative laboratory experiments in the new science offer revealing analogies for constructivism, namely new pictures of how humans interact with each other and the environment. These conceptions lead to roles for teachers with the potential to revolutionize education in much the same way that quantum discoveries revolutionized Newtonian science.

Background and Rationale

My entry into this discussion began with a column I wrote for the American Psychological Association titled "Quantum Educational Psychology: Classrooms as Vast Porridges of Being" (Scheurman, 1998). At that time, I was inspired by a book titled *Leadership and the New Science: Discovering Order in a Chaotic World*, in which Margaret Wheatley (1997, 2006) deftly links organizational dynamics and corporate success to recent discoveries in biology, chemistry, chaos theory, and especially quantum physics, collectively referred to as the "new science." This led me to other revolutionary thinkers such as Dana Zohar's *The Quantum Self: Human Nature and Consciousness Defined by the New Physics* (1990). Since then, my bookshelves have filled with metaphorical references to describe human consciousness and other strange phenomena, all coined and elaborated on by credible physicists. Consider a "turbulent mirror" (Briggs & Peat, 1989), "dancing Wu Li masters" (Zukav, 2001), or an "implicate order" in the universe (Bohm, 1980), characterized by what one quantum scientist refers to as a "green dragon" (Swimme, 1984).

Whereas the new science is rife with images and ideas to guide research and theory in fields such as physics, no consistent metaphor has been christened to capture and communicate the worldview of learning that constructivism encompasses.[2] I posit that the relationships observed in a jazz session among players (learners), director (teacher), and a musical chart (curriculum) possess a quantum quality. Music professor and theorist Edward W. Sarath (2013) agrees, using the term "integral theory" to capture the transformative powers of improvisation, suggests that the historical, cultural, and spiritual consciousness at the heart of jazz has the potential to catalyze an entirely new non-materialist worldview that can aid psychological development for the individual as well as inform educational reform in society. Others, such as Jonah Lehrer (2008), analyze the unique processes of listening to music, suggesting that noise becomes harmony as a result of what happens in the individual brain as much as what is produced by performing musicians. The result of these explorations is a perspective on music

[2]I published a paper in which I offered two metaphors for the role of students in a "constructivist" classroom – naïve scientist (for cognitive constructivism reflected in the work of Piaget) and apprentice (for social constructivism derived from Vygotsky). See Scheurman, G. (1998).

through the innovative lens of quantum physics, which I see as an invitation to articulate a new paradigm in learning theory and adopt a synthesizing exemplar for effective teaching. The conversation is important because whichever metaphor becomes the face of a new paradigm is likely to shape the collective culture of classroom practice.

Quantum Learning Theory

An empirical basis for the application of new science in education is beginning to appear as studies in quantum cognition and mental modeling explore new avenues for how the brain functions (e.g. Busemeyer, 2015; Kitzbichler, Christensen, & Bullmore, 2009). This includes the realm of music and the brain (e.g. Jourdain, 2008). The divide between classical and quantum physics is also finding its way into mainstream journals (Pincus, 2009) and popular media (Tyson, 2017). Where physicists once described the universe in terms of tiny billiard balls moving around by contact forces (a Newtonian perspective), they now use words like *contextualism* and *continuous spontaneous localization* to describe the subatomic world (a quantum perspective) (Folger, 2018). I have identified five accessible principles with implications for constructivism and the future of learning theory that have emerged from this dialogue. The examples I will share all come from education. However, each principle has implications not only for the way we teach and learn, but for how we function in other realms as well, be they intellectual, emotional, vocational, or professional.

Disequilibrium Leads to Self-organizing Systems

Physicists today talk of concepts like *autopoiesis*, referring to the intriguing paradox that while every structure in the universe has a unique identity and a clear boundary, no structure is ever at rest. It is always renewing itself, merging with other structures, weaving a web of dynamic inter-connectedness with its environment. In Chemistry, for example, solutions sometimes oscillate between two different states rather than existing as only one. In such systems, an entity will give up its form in order to recreate itself, guaranteeing the long-term vitality of its environment. Researchers use language such as "exquisitely ordered behavior," "evanescent structures waiting to be born," and "continuous dance of energy" to describe these apparently altruistic interactions at the molecular level (Wheatley, 2006, pg. 39, 80). Musician and poet Stephen Nachmanovitch picks up this theme of self-organizing systems that occurs both in nature, as seen by the evolution of an ocean's ecosystem, and in music, as experienced in the free play of a jazz ensemble. In both cases, "the self-organizing activity arises, slowly changes, suddenly shifts, learns from mistakes, interacts with the ways of its fellows and the environment" (p. 33).

Fearing instability, educational leaders often strive for control by imposing strict and uniform standards, limiting teachers' freedom and inhibiting small changes that might threaten authoritative control at the local level. Unfortunately, this often creates conditions that interrupt self-correcting rhythms and threaten the health of the overall system. Disequilibrium in a quantum system does not lead to instability; it reflects a dynamic structure in a constant state of renewal. Applying this knowledge to the world of business, Wheatley invites corporate managers to instill a revolutionary spirit – she calls them "equilibrium busters" – who disturb the peace in order to guarantee vitality of the company (pg. 108). I seldom start a lesson without fostering dynamic discomfort, or what Piaget called cognitive disequilibrium, creating a puzzling or perturbing experience to kick-start the learning process. If learning theorists would focus on Piaget's presciently quantum spirit, they might lead educators to new insights about classroom environments. For example, instead of imposing artificial constraints in hopes of gaining stability and control, they could help us identify self-organizing methods that actually encourage the very things that atomic particles – and young children – have naturally gravitated toward for years, things like novelty, disequilibrium, and an absence of control.

There is Beauty and Order in Chaos

One community of discussion uses the term "chaos" to describe any dynamic system that is driven by the perpetual need for equilibration amid contradictory and complimentary forces. Piaget once again recognized this phenomenon as an inherent element of human cognition, describing how processes of assimilation and accommodation perform an intimate dance leading to the development of mental models. This is consistent with chaos theory, which reveals how there is symmetry and elegance in environments that appear to be random and disorderly. In new science, for example, the merging of relativity and quantum mechanics has yielded discoveries including laser technology and cell phones, even though those theories are themselves incompatible in many ways. In fact, there is so much order in the world that attempts to isolate discrete moments often create an illusion of disorder. Researchers discover balance and harmony in apparently chaotic systems based on "a constant weaving of relationships, merging energies, and constant ripples that occur within a seamless tapestry" (Wheatley, 2006, p. 36). Another example of chaos theory at work is an artistic representation of ineffable beauty called a fractal, which is generated when a computer repeats millions of iterations of a simple geometric transformation. Fractals are a way of measuring irregularities in the world, evoking a "deep recognition" of so-called *strange attractors* (Gleick, 1987). These magnetic forces are so powerful that even seemingly chance occurrences (errors) remain inextricably connected to a prescribed boundary. When a system is looked at holistically, scientists are forced to conclude that everything affects everything else.

Such discoveries led one post-modern psychologist to adopt a metaphor from quantum physics known as the "butterfly effect" to explain incongruities in student behavior and classroom ecosystems (Reynolds, 2005, pp. 18 ff). This metaphor becomes manifest in modern physics when minute differences in chaotic situations produce gigantic results. A classic example is when a single grain of sand affects the initial trajectory of a boulder falling down a mountain so that by the time it reaches the bottom, the boulder is on the other side of the mountain. In business, Wheatley argues that a whole new vista appears when leaders abandon their myopic attention to pre-ordained outcomes in order to see the shape and beauty of a problem emerging out of myriad and sometimes minute variables that contribute to its institutionalized and recursive patterns.

Modern physicists often describe the entire universe in similar terms, as well as individual human beings, who represent a microcosm of that grand system in the way a seemingly diverse array of unrelated parts maintain togetherness as an elegant functioning whole. One physicist (Swimme, 1984) describes our unique beauty in this way: "The Ultimate Mystery from which all beings emerge prefers Ultimate Extravagance, each being glistening with freshness, ontologically unique, never to be repeated. Each being is required. None can be eliminated or ignored, for not one is redundant" (p. 61-2).

As a teacher, I have learned to look for the elegance of each individual as it exists within an environment of recurring patterns instead of jumping for a quick behavioral recipe in hopes of reducing the commotion in my classroom. Armed with insights from new science, I even invite a certain level of chaos by embracing improvisation, a tolerance for failure, and academic risk-taking. Learning theorists armed with quantum scientific data might help teachers learn to "liberate the complexity hidden within [a system], giving access to creative potential" (Briggs & Peat, 1989, p. 104). As we shall see, this is eerily similar to the way jazz aficionados describe their craft as well.

Perspective and Context are everything

In the physics laboratory, particles have been known to disappear in thin air, make quantum leaps, and even change form and property as they respond to one another and to the observer. Furthermore, subatomic entities exist as both particle and wave until a scientific apparatus intervenes and tries to capture their behavior, sometimes even acting as if they know where the observer is *planning* to look (Ball, 2017). Scientists end up resorting to mystical explanations. One (Wheeler & Zurek, 1983, pg. 199) refers to the ultimate constituent element of the universe as an "ethereal act of observer-participancy" where "observers are necessary to bring the world into being" (see also Talbot, 1993, where this source is quoted).

What if educational researchers embraced the fact that they disturb the outcome of any observation? Instead of slicing institutional activities into finer gradations and living under a pretense of objectivity, we might step back and gain a fuller view that includes the assessor, thereby channeling the power present in a quantum system. I recently witnessed an exaggerated example of the observer-participant effect when teachers in a local middle school were administering a so-called "common assessment." One teacher included hands-on objects and student interaction as part of the assessment activity, while another yoked pupils to their desks and demanded silence in order to guarantee "independent" performance and no cheating. Even though the actual product – the test – was the same in the end, the conditions surrounding the performance rendered the notion of "common" assessment almost ridiculous. The new science has a lot to teach educators about consequences of ignoring the evaluator's role in student progress without taking perspective and frame of reference into account.

Nothing Exists Without Relationships

Physicists (Zohar, 1990, pp 98 ff) describe how particles (called fermions) "keep to themselves" until other tiny elements (called bosons) draw them together, giving us the everyday world of materialism. Light particles (called photons) exhibit "bunching" properties, while electrons seem to communicate, exhibiting "quantum entanglement" by maintaining a perfect correlational spin with each other even when separated by very long distances. It is a stretch for some people to talk about minute constituents of the universe in such personified terms. I find it exciting and entirely plausible that relational behaviors among the tiniest elements of everything in the universe cumulate and concentrate in forms such as myself and help explain the nature of existence and consciousness. In fact, they become components for helping me understand my ability to think and learn as well as attitudes and behaviors of my charges that are sometimes so difficult to grasp.

What if we challenged ourselves to observe students and classrooms the same way physicists have come to view these surprisingly gregarious phenomena? Insights from the world of "quantum interconnectedness" and "relational holism" might help us learn to view people within our organizations as "bundles of potentiality" (Wheatley, pp. 34 ff) instead of misfits who do not fit our standardized molds. Truth told, new science has been surreptitiously shedding light on post-modern theories in cognitive psychology for decades. Consider Vygotsky's popular conceptualization of a zone of proximal development, which implies that different settings and conditions interrelate to evoke particular attributes from people while others remain dormant (Vygotsky, 1978). My personal experience of seeking to apply quantum ideas yields similar "patterns of active relationship," as students "tease … with their elusive double lives" as both a unique personality (mass) and expression of that spirit (energy). Awareness of what happens in the subatomic laboratory has allowed me to better understand how the free play of thought, allowing creative intelligence to enter into relationship with opposition and contradiction, is the path to transformation and meaning. Once again, my experience with musicians also suggests that this is an accurate explanation for the way things work in jazz ensembles and unconventional orchestral arrangements, which we will return to following our fifth principle of new science.

Wholeness and Unity are found in Freedom and Diversity

Metaphorical candidates from the quantum world poised to replace "mind as machine" in psychology include the fractal and the hologram. Both possess a unique feature, namely that smaller pieces of each one mirror the entire form of the larger structure. Unlike fractals, however, which are produced by recurring self-similar patterns, holograms occur when interfering waves are projected onto a photosensitive surface. "Holograms describe the deep construction of matter and movement of energy. …[F]ractals describe the shapes that matter takes and the orderly and chaotic processes that transform those shapes" (Briggs & Peat, 1989, pg. 112). Taken together, researchers are beginning to believe that every phenomenon in the physical world represents a microcosm of the whole. Physicists have articulated a "principle of complementarity," speaking of elementary matter in terms of its whole identity, since it can show up simultaneously as particles, discrete points in space, or as waves, energy dispersed over a finite space. One of the grandparents of quantum understanding, David Bohm, identifies many examples – e.g. Cartesian coordinates within calculus and the "enfolding" of dye into a viscous fluid – that demonstrate how traditional notions of disruption in a system affects the entire system, resulting in a sort of "total order" rather than subdivided parts of a system behaving differently (Bohm, 1984, p. 149). Since Bohm's groundbreaking work, neuroscientists have begun to discover that memory and other mental functions are distributed across the entire brain, a finding that may hold across the entire universe as well (Pribram, 2007). The curious conclusion of all this work is that when constituent elements of any system are allowed to operate freely and express their uniquely diverse multiple personalities, the result is an exquisite orderliness in the overall system. Psychiatrist Stanislav Grof (1993) points to holography as both the metaphor and scientific model for understanding cognition and consciousness, referring to the human system as a "holotropic mind."

Perhaps education should give credence to what quantum scientists have already accepted, namely that analysis into parts, precise prediction of outcomes, and replication of results – hallmarks of the Newtonian paradigm – are virtually impossible. Modern physicists willing to stretch our conceptions of the discipline remind that many systems have an implicate order, where "one has to observe [a] new situation very broadly and tentatively, to 'feel out' what may be … relevant new features. From this, there will arise the discernment of [a] new order, which will articulate and unfold in a natural way" (Bohm, 1980, p. 148). Shifting our perspective to the unity of every system does not mean we need to give up individuality or attention to diversity. On the contrary, a quantum psychology may help us understand the indivisible character or "innate image" (Hillman, 2004) and unique interests that develop from the unique "spiritual embryo" of every child (Montessori, 1936), while simultaneously recognizing each individual as part of "an act of understanding in which the totality … is an actual process that, when carried out properly, tends to bring about a harmonious and orderly overall action" (Briggs and Peat, 1989, pg. 56).

Musical Improvisation: A Quantum Metaphor for Teaching

The new science is entering its second century since tipping from a materialist into a post-materialist paradigm. Educators don't need to wait another century for brain research and educational psychology to catch up to physics before tapping into the power of quantum understanding. Constructivist theory is already replacing information processing as the next chapter in the cognitive revolution, injecting variables like emotion, spirit, and context back into the equation.

Meanwhile, as I have been hinting throughout this paper, excellent models from the field of music demonstrate how quantum principles may be applied outside of disciplinary science (Halpern, 2014; Leaderman, 2011). Margaret Wheatley (2006) once again reminds us that music has profound relevance to education (inserted *italics* are mine):

> Those who have used music metaphors to describe working together, especially jazz metaphors, are sensing the nature of this quantum world. The world demands that we be present together and be willing to improvise. As leaders [*teachers*], we play a crucial role in selecting the melody, setting the tempo, establishing the key, and inviting the players [*learners*]. But that is all we can do. The music comes from something we cannot direct, from a unified whole created among the players – a relational holism that transcends separatism. In the end, when it works, we sit back, amazed and grateful (pg. 44).

I will now turn attention to two exemplars of improvisation that demonstrate the power inherent in any quantum system, whether in the physics laboratory or rehearsal room.

Coltrane – Improvisation in the Mind (and Hands) of the Producer

In *The Jazz of Physics* (2016), a saxophone-playing scientist named Stephon Alexander analyzes the unusual genius of musicians such as John Coltrane through the prism of quantum mechanics. Among his creative observations, Alexander suggests that "the wonderful thing about physics [*and jazz*] are those moments when the 'rules' that we think are unchangeable are broken" (pg. 135, *italics* mine). He goes on to demonstrate how interfering wave functions and repeating patterns in the quantum world are analogous to soloists conversing with each other during a jazz session. Accidental and even intentional "wrong" notes send a ripple effect that drives a sort of divine geometry in any musical universe. He coins the term "improvisational physics" (pg. 7) to explain how a driving frequency inserted into a sound system will sometimes cause a spike in oscillations that results in a cosmic harmony when it happens to match natural frequencies inherent in the noise. Similarly, to a jazz musician, the music is already in one's head. The key to improvisation is not magically divining the correct frequency but *discovering* that frequency from among the infinite possibilities revealed in the relationship that exists among the performers, their instruments, and the sound itself.

Musician and author Edward W. Sarath extends the connection between music and science by making the case for applying quantum principles found in jazz to teaching and learning. In his book, *Improvisation, Creativity, and Consciousness: Jazz as Integral Template for Music, Education, and Society* (2013), Sarath analyzes Coltrane's (among others') contributions in the context of a larger theory where "jazz's improvisation-based process scope renders it a uniquely powerful tributary that flows not only into the overarching musical ocean but the broader oceans of creativity and consciousness" (pp. 3-4). What is "integral" about Integral Theory is the way bridges are built – e.g. between ancient shamanist sagacity and breakthroughs in cognitive neuroscience – as ways to tap into a quantum-like consciousness he describes as an "inner-outer totality" (2). As for the role of music, he says: "Within the arts, …, the creativity-consciousness relationship is uniquely embodied in the improvisation-based musical art form of jazz, pointing to the potential for this idiom to assume leadership in the arts-driven integral revolution (p. 3)." Furthermore, Sarath suggests that any paradigm shift in society must begin in our educational systems, and that by inhibiting practical and theoretical inquiry into the interior, transcendent dimensions of human nature central to creativity and consciousness development, education may perpetuate the very paradigm that needs to be transformed. This is exactly what I am suggesting in this paper, and the reason I offer constructivism and improvisation as replacements for materialism and the information processing as a metaphorical guide for learning theorists and teachers in the 21st century.

Stravinsky – Improvisation in the Mind of the Beholder

Improvisation can also occur in musical genres other than jazz. For example, a classical composer might choose to improvise by imposing or removing conventional structures in a way that leaves listeners in a considerable state of disequilibrium. This occurred in Paris when Igor Stravinsky's symphonic ballet titled *The Rite of Spring* debuted in 1913. Sophisticated patrons attended the concert with expectations to see and hear things that would be consonant with traditional and familiar musical forms. What followed was a series of discordant sounds and the appearance of erotic ballet dancers so shocking to audience sensibilities that riotous mayhem broke out in the concert hall. An insightful analysis of Stravinsky's genius is provided by Jonah Lehrer, who in *Proust Was a Neuroscientist* (2008) reveals how deep insights expressed in the work of musicians, poets, artists, and even chefs have often foreshadowed findings of modern neuroscience. In reference to *The Rite of Spring*, the agitated audience in 1913 could hear nothing but violation of the melodic rules they had come to expect, which Lehrer argues must have been the composer's plan based on his prescient awareness of how any listener attends to music:

> What separated Stravinsky from his rioting audience that night was his belief in the limitless possibilities of the mind. Because our human brain can learn to listen to anything, music has no cage. All music needs is a violated pattern, an order interrupted by a disorder, for in that acoustic friction, we hallucinate a feeling. Music is that feeling. The Rite of Spring was the first symphonic work to celebrate this fact. It is the sound of art changing the brain. (p. 143)

Or, in the case of Coltrane's colleague John Cage, it might even be silence that causes the ultimate disruption forcing "listeners" to transform the meaning of music itself.[3] Lehrer suggests that the role of improvisation extends beyond

[3]The reader may recall the famous performance by John Cage titled *4'33"*, in which the artist invited his audience to sit in silence and absorb the sounds of the immediate environment for three movements totaling four minutes and 33 seconds. See an NPR story about the composition at: https://www.npr.org/ 2000/05/08/1073885/4-33

composer, choreographer, conductor, and performer to include listeners as well. He goes on to say that "whenever a noise [*or its noticeable absence*] exceeds our processing abilities … the mind surrenders. It stops trying to understand the individual notes and seeks instead to understand the relationship between the notes" (pg. 130, *italics* mine). Much like physical systems revealing mysteriously generative and even "social" behaviors of fermions, bosons, and other strange forces in the quantum laboratory, "music only excites us when it makes the auditory cortex struggle to uncover its order." Thanks to its plasticity, the human brain confronted with such challenging stimuli evokes a quantum response, so that in time people can find equilibration and enjoy any music. By denying listeners the thing they thought they wanted most, namely familiar and accessible patterns, Stravinsky was only providing something that appealed even more to his befuddled listeners, namely novelty and the necessity for *them* to create harmony out of dissonance in their own mental and emotional systems.

I wonder if a similar intuition is what drove artists like Vincent Van Gogh or Bob Dylan, whose forms and messages challenged audiences so much that they too had to discover their own harmonies in the foment. To his own question about *The Rite of Spring* – "how does an oblivion of noise become a world class symphony?" – Lehrer answers that it is the brain's unique ability to change itself through experience. Neuroscience even steals vocabulary from music, naming malleable brain cells a "cortico*fugal*" network after the fugue, a musical form that Bach made famous. Music, like quantum systems and chaos theory, "works by subtly toying with our expected associations, enticing us to make predictions and then confronting us with our prediction errors" (pp. 140-1).

Synthesis of Quantum Science and Musical Improvisation

What happens when we view Coltrane and Stravinsky, along with the audiences that continue to be arrested by their creations, in terms of the new science? Can we apply principles of quantum physics extrapolated from their processes and products to worn-out forms that persist in materialist classrooms? I have suggested five elements that might shift the paradigm from mechanistic inhibitors to liberating facilitators of dynamic learning encounters: (1) disequilibrium that kickstarts self-organizing systems; (2) apparent chaos that contains and leads to elegant expressions of striking beauty; (3) the irreducible ubiquity of perspective and context; (4) the reality of relationship as a condition of everything that exists; and (5) freedom and diversity that emerges when we shift from a focus on components and categories to an awareness of wholeness and unity.

The necessity of embracing a seamless material world where these principles serve as guiding lights, even when they sometimes appear to us in apparently contradictory ways, demands that we find an inclusively novel framework for reality. This creates a unique variation on Kuhn's notion of a revolutionary paradigm shift in modern science. Enough anomalies exist in quantum experiments to render much of Newtonian science obsolete, and yet traditional physics still explains enough about the observable world that old and new science are finding ways to co-exist and merge in the service of new understanding. This is where the arts, and especially music, enter the scene and provide a bridge to the world of education. Notice how Nachmanovitch (2018) couches musical improvisation using quantum scientific vocabulary:

> "Einstein did not overthrow or invalidate Newton's laws, but rather uncovered a deeper context that encompassed both the familiar laws of mechanics and the new, strange phenomena of electromagnetism. As ideas evolve, there occurs a rhythm of systole-diastole between the rejection of mistakes and accidents, their acceptance as oddities, and their incorporation along with the old system of beliefs into a richer, more complex system" (p. 106).

This expansive and delimiting view of reality, one that acknowledges the role of improvisation as a central feature guiding the processes of learning and development, can be daunting to a teacher whose primary concern is maintaining control and producing stable test scores in a chaotic world. Perhaps it will comfort these wary professionals to know that a classroom that embraces chaos is not without boundaries, nor need we sacrifice our unique integrity on the sea of relativistic randomness and quantum uncertainty. Even improvisation has its own rules; it's just that those are not *a priori* rules. Nachmanovitch (1991) explains it this way:

> When we are totally faithful to our own individuality, we are actually following a very intricate design. This kind of freedom is the opposite of "just anything." We carry around the rules inherent in our organism. As living, patterned beings, we are incapable of producing anything random. We cannot even program a computer to produce random numbers; the most we can do is create a pattern so complex that we get an illusion of randomness. . [*What we are describing*] is a dialogue with the Self – a dialogue not only with the past but with the future, the environment, and the divine within us. As our playing, writing, speaking, drawing, … dancing, [*or teaching*] unfolds, the inner, unconscious logic of our being begins to show through and mold the material. The rich, deep patterning is the original nature that impresses itself like a seal upon everything we do or are (pp 26-7).

Another assumption of materialist thinking, implied by the second law of thermodynamics, is that the world of matter and energy follows a natural course from order into disorder. Post-materialist thinking demands that we embrace an alternative view, one where "life reveals the inherent countercurrent to this tendency, transforming matter and energy into more and more organized patterns through the ongoing game of evolution. This proliferation of variety seems to be self-energizing, self-motivating, and self-enriching, like play itself " (p. 45). Inherent in this worldview is the primary importance of "mistakes." I use quotations because, like any quantum system, nature really doesn't consider its own anomalies as wrong per se, but simply opportunities to enrich and sustain itself over the long term.

In the classroom, as in the rehearsal room or on stage, one can adopt a traditional attitude, treating mistakes as something to avoid and rue or revile when they happen. "Or [one] can repeat [the mistake], amplify it, develop it further until it becomes a new pattern" (p. 9). Similar to earlier descriptions of environments in physics, biology, and chemistry labs, "[one] can drop neither the old pattern nor the new one but discover the unforeseen context that includes both of them" (p. 9). Applied to education, this eliminates the basis for much of the standardization and specialization so prevalent in schools today. Buttressed by music, Nachmanovitch (2018) makes two bold claims that are also relevant. First, there is no such thing as a "note" in music, since a note is only an abstract symbol representing a tone which is an actual sound. Even the same note will vary along some more or less perceptible dimension so that even someone playing "out of tune" is only doing so according to a preconceived benchmark of what is considered "*in* tune." Consequently, "each vibratory event is unique" (p. 61) and nothing can be standardized. Second, monoculture is anathema to learning. In chemistry and biology, it means loss of options, which invariably ends up in instability. On the other hand, "the exploratory spirit thrives on variety and free play – [even though] many of our institutions manage to kill it by putting it into small boxes in the hopes of avoiding anything that strays from the norm. They tend to divide learning into specializations and departments" (p. 118).

Embracing a bold new vision of reality is a challenge, to say the least, especially in institutions like education notoriously impervious to change. I am only one of an increasing number of pioneers recognizing the potential of reaching beyond materialistic explanations and calling us to consider a post-materialist worldview. I have already referenced Professor Sarath (2013), who offers improvisation as an archetypal pathway to transcendence, with invention, positive interaction, and personal individuation serving as outcomes of a consciousness rooted in jazz tradition. Similarly, at the intersection of poetry, music, philosophy, and new science, popular and credible physicists like Carlo Rovelli summarize what exists on the horizon for those willing to look ahead:

> A handful of types of elementary particles, which vibrate and fluctuate constantly between existence and nonexistence and swarm in space, even when it seems that there is nothing there, combine together to infinity like the letters of a cosmic alphabet to tell the immense history of galaxies; of the innumerable stars; of sunlight; of mountains, woods, and fields of grain; of the smiling young faces of the young at parties; and of the night sky studded with stars." (pp. 37-38)

Why would we not include individual students and teachers in this list as they experience victories and vicissitudes in the context of their classrooms and schools? Rovelli reminds us of the need to be patient with persistent worldviews even as we challenge ourselves to embrace this new mindset. Standard models of thinking may not be very elegant, he says, although they continue to work remarkably well at describing much of the world we interact with every day. Although I agree, I also resonate with this scientist's charge that "perhaps on closer inspection, it is not the model that lacks elegance. Perhaps it is we who have not yet learned to look at it from the right point of view, one that would reveal its hidden simplicity" (pg. 37). It is to this new view of matter, music, learning, and teaching, that I am trying to direct our attention.

Conclusion and Challenge to Education

In this paper, I have dared to add pedagogy to the list of human enterprises reaching into quantum realms in hopes of finding a ray of philosophical and theoretical illumination. To that end, I have referenced a band of creative experts who have already built bridges between science and music, and there are more (e.g. Jourdain, 2008). One of my primary references is Stephen Nachmanovitch – violinist, composer, poet, and teacher – whose book titles include *Free Play: Improvisation in Life and Art* (1991) and *Art Is: Improvisation as a Way of Life* (2018). Without explicitly referencing new science to explain the role of improvisation in human development and learning, Nachmanovitch uses the language of quantum physics to explain everyday functions such as talking, or a baby learning to walk:

> … when toddlers fall, they don't need to be told that they fell. We trust that they know what is happening as it happens, that they receive feedback as the experience unfolds. Our bodies and minds, our partnerships with others, are self-organizing systems. The mechanisms of feedback, communication, self-correction, self-organization, by which toddling evolves into graceful interaction, are fundamental to life, as revealed in the sciences of systems theory" (2018, pp. 61-2).

The author goes on to refer to us all as "ex-toddlers," engaged in perpetual "falldown—getup" cycles, collecting information and embracing our mistakes in a world where "improvisation is trial and error smoothly flowing" (p. 62). To say that this excites me is a profound understatement. As an Educational Psychologist and life-long teacher, I learned long ago that one of the irreducible keys to both development and learning is the need for learners to have their apple carts upset. Call it puzzlement, perturbation, cognitive disequilibrium (Piaget, 1985), or dynamic discomfort (Joyce, 2018), without disruption in the fabric of our schemata for the world as we think it exists, our experience of that world remains static and inert. This has always been the role performed by artists and musicians. And scientists. Whereas the poet struggles to find a new metaphor, the writer a "novel" narrative, the artist a new perspective, the composer an undiscovered pattern, the scientist looks for a unifying theory to encompass others. This is where quantum physics meets musical improvisation meets educational theory meets pedagogical practice. The teacher's success is in finding something original enough to arouse an emotional response from learners whose neurons must be stretched to understand it.

Explorers alike – cosmologists, composers, painters and performers – stand back in awe every time they embrace chaos and discover order in apparent randomness. If the role of teachers is to help "sculpt" children from uncarved block into innate image that already inheres in their inner being, as well as guide them on how to experience and contribute to the ultimate elegance and harmony of their internal and external worlds, then perhaps it's time they take a lead from quantum revelations and the music spawned in their wake. This means paying attention to the paradigm-shifting principles we are learning from new science, as well as the way musicians have been unwittingly applying those principles for centuries. This marriage between science and performing arts is where development and progress occur, both at the individual and interdisciplinary level.

The integration of quantum principles into realms outside of physics should be a beacon for educational researchers and teachers, often the last to recognize or embrace their uneasiness when the earth begins shifting just outside the walls of the classroom. As a link between the work of evaluator and practitioner, imagine if learning theorists could step out of the boat of their Newtonian assumptions and procedures and view children as instances of unfolding beauty. A quantum perspective would open new vistas of understanding about the natural frequencies of every child and the vibrational patterns experienced in classrooms. If improvisation is what particles do in a quantum universe, and what Coltrane modeled was a quantum experience, then what happens in making jazz stands as an exemplary model for teaching. Similarly, if what Stravinsky demonstrated in breaking the conventions of classical forms is a quantum undertaking, his process might become a guiding metaphor for composing curriculum. Both cases demonstrate improvisation in its most elegant form. Just as jazz musicians and classical composers push the envelope in search of new disciplinary paradigms, teachers and their charges must push the limits of form, function, and substance in order to discover and construct meaning together. Like physicists, or connoisseurs of music, they might be able to sit back, amazed and grateful for the breathtaking sights and sounds emanating from the classroom.

Elsewhere, I have suggested new metaphors for the role of teacher (Scheurman, 1998). Instead of "transmitter" in a behaviorist world or "manager" in one that recognizes learning as a matter of information processing, constructivism invites teachers to recognize students as "naïve scientists" or "apprentices" who facilitate and collaborate in the process of interpretation and transformation of information into meaning. But what about classrooms and teachers themselves? Here is how Margaret Wheatley, herself citing others, describes the elegant new universe: "Because the quantum world is so strange, its chroniclers reach for new metaphors. Zohar depicts it as a 'vast porridge of being where nothing is fixed or measurable … somewhat ghostly and just beyond our grasp' (1990, 27). Capra sees it as 'dynamic patterns continually changing into one another – the continuous dance of energy' (1983, 91). … In 1930, astronomer James Jeans created [an] image of this new world: 'The universe begins to look more like a great thought than like a great machine' (in Capra 1983, 86)."

My hope is that researchers, administrators, and especially teachers will pay heed to these elegant new vistas, less mechanically and more metaphorically, looking for signs of quantum improvisation in their role as collaborator and conductor in a jazz band while expanding their view of classrooms as vast porridges of being.

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