Creativity and Innovation:

A Complex Adaptive Systems Theory

by

Philip A. Lambert

MBA, University of New Brunswick, 1995

BESc, University of Western Ontario, 1984

A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of

Doctor of Philosophy

in the Graduate Academic Unit of Interdisciplinary Studies

Supervisor:	Mary Blatherwick, PhD, Faculty of Education
Examining Board:	David Foord, PhD, Interdisciplinary Studies John McLaughlin, PhD, President Emeritus & Professor Emeritus Engineering Thomas Mengel, PhD, Renaissance College
External Examiner:	Jenifer Adams, PhD, Prof and Chair, Creativity and STEM University of Calgary

This dissertation is accepted by the
Dean of Graduate Studies

THE UNIVERSITY OF NEW BRUNSWICK

March, 2019

Abstract

Creativity and innovation research has been hampered by the lack of an over-arching, internally consistent theoretical framework. This dissertation developed the initial parts of a comprehensive complexity theory of creativity. This is an articles-based dissertation, consisting of three articles that make individual contributions to an overall complexity theory of creativity. Each article established a potential link between creativity and one characteristic of complex adaptive systems. One argued for the equivalency of creativity and emergence, a primary characteristic of complex adaptive systems, while another showed how the paradoxes identified through decades of creativity research can be explained by another characteristic of complex adaptive systems, the order-chaos dynamic. A third article argued that the small-world networks associated with complex adaptive systems predict that diffusion-of-innovation patterns will be unpredictable, not normally distributed, as has been the dogma of business school texts for decades. A small number of datasets were analyzed, and the results support this prediction. In the concluding chapter, the results of the three articles have been brought together and a complex adaptive systems model developed. The model incorporates creativity as a central feature and includes continuous evolution and a feedback loop that yields increasing complexity. Together, these three articles represent a strong case for recognizing creativity as a characteristic of complex adaptive systems and for continued efforts along this line of research.

Dedication

This work is dedicated to my grandson, Grayson Lambert, who always inspires creativity, and in loving memory of my father, Peter Lambert, whose curiosity and creativity kept him young his whole life. Self-similarity is evident across the generations.

Acknowledgments

This dissertation would not have been possible without Dr. Mary Blatherwick, who did not hesitate when I asked her, shortly after meeting for the first time, if she would supervise my work as an interdisciplinary studies PhD student researching creativity. Dr. Blatherwick gave me the latitude I needed to explore two very large topics, and the guidance and support required to make some progress in merging creativity and complexity. Her support and encouragement have been invaluable. I would also like to thank committee members/advisors Dr. Rob Austin and Dr. Robert Kelly for many helpful review comments. Thank you to Dr. Jeffrey Picka, for his review of my statistical approach in the second article of this dissertation. I want to particularly thank Dr. David Foord for always providing wise counsel, thorough reviews, and the time required for me to talk through some of the more complex parts of my emerging theory. I recognize and appreciate how fortunate I have been to receive such tremendous support. Thank you all.

I also wish to acknowledge my three creative children, Melanie Lambert, Jason Lambert, and Andrew Lambert, for engaging with and supporting my curiosity and for moral support while I pursued further education.

Table of Contents

List of Tables

List of Figures

1 Introduction: Why Study Creativity

Over 40 years ago Paul Torrance (1970) commented that "Children are so accustomed to the one correct or best answer that they may be reluctant to think of other possibilities or to build up a pool of ideas to be evaluated later" (p. 86). Despite his best efforts, and the efforts of many others, creativity scores are declining in the United States (K. H. Kim, 2011).[1] Could North America be losing a creativity race, a race we may not even know we're in; a race that may be more important than most of us realize; a race that is not between various regions of the world, but one that we're all in, together?

In *A Whole New Mind* Daniel Pink (2006) argues that the 'advanced' world is undergoing a shift from the information age to a conceptual age and that it is inventive, creative, and empathetic people who will thrive in this new world. "The most creative among us see relationships the rest of us never notice. Such ability is at a premium in a world where specialised knowledge work can quickly become routinized work – and therefore be automated or outsourced away" (p. 135). James Kaufman and his colleagues (2008) noted in *Essentials of Creativity Assessment* that "Because creativity, specifically the ability to solve problems creatively, is so universally useful, its relationship to any construct or aspect of human life is worthy of study" (p. 126).

It seems to be universally acknowledged that creativity is a desired trait. It even ranks as the most used (perhaps overused?) word in LinkedIn profiles. According to Erick Schonfeld in *The Rise of the "Creative" Class* (2011),

---

[1] To be more precise, divergent thinking scores are declining. Some creativity researchers (for example, Torrance, 1988) argue that divergent thinking is a good measure of creative potential.

> In a time of high unemployment when traditional skills can be outsourced or automated, creative skills remain highly sought after and highly valuable. We all want to be part of the creative class of programmers, designers, and information workers. The term used to mean artists and writers. Today, it means job stability. (para. 2)

This dissertation will argue that the world is in a constant state of flux and whether one is causing creative destruction, avoiding it, or recovering from it, creativity is required, and more is needed as the pace of change continues to accelerate. Most mainframe computer manufacturers disappeared in the space of a few years. The entire life cycle of the video rental business was barely more than two decades.[2] Publishers of printed works have either reinvented themselves or died. The music industry has been transformed, seemingly overnight. Commonplace products, such as the thermostat and the smoke detector, are being given a new lease on life through enhanced functionality, coupled with an improved user interface and attention to aesthetic appeal, and they're commanding large price premiums for getting it right (see, for example, www.nest.com/ca/). The once proud Canadian technology giant – Nortel – is now but a memory and Blackberry was close to following suit. Cars are becoming entertainment centres and communication hubs that can also get you where you want to go while looking great doing it. 'Innovate or die' isn't just a catchy slogan. It seems that everywhere you look these days the business landscape is littered with the burned-out hulks of those companies that did not innovate fast enough. So it should come as little surprise that an IBM survey of 1,500 CEOs from around the world found that creativity was the number one competency that had to be instilled throughout an

[2] Blockbuster, which became the largest video rental chain, was launched in 1985, but didn't become commonplace until around 1990. They filed for bankruptcy in 2010 (Phillips & Ferdman, 2013).

organization in order to be successful (IBM, 2010). These CEOs valued creativity over management discipline, integrity, even over vision.

In *Rise of the Creative Class – Revisited* Richard Florida (2012) suggests that we are undergoing a change at least as dramatic as the industrial revolution:

> It wasn't just the Internet, or the rise of new technologies, or even globalisation that were upending our jobs, lives, and communities, though all those things were important. Beneath the surface, unnoticed by many, an even deeper force was at work—the rise of creativity as a fundamental economic driver, and the rise of a new social class, the Creative Class. (p. vii)

However, t's not just corporations and the economy that need and value creativity. The human race faces global issues unprecedented in scope, scale and complexity. Complex political, social, resource, and environmental issues demand our most creative solutions, or entire societies – if not the entire human race – may go the way of the mainframe computer. Karpova, Marcketti, and Barker (2011) concluded that "Creativity becomes the focus when preparing current students and future citizens to deal with uncertainty and to adapt to continuous change both personally and professionally" (p. 53) while Csikszentmihalyi (1996) noted that "for better or for worse, our future is now closely tied to human creativity" (p. 6). Arnold Toynbee (1962) in *Has America Neglected Her Creative Minority?* argued that:

> This is all-important, because the outstanding creative ability of a fairly small percentage of the population is mankind's ultimate capital asset… the work of creative spirits is what gives society a chance of directing its inevitable movement along constructive instead of destructive lines. (p. 9)

So much of what makes life worth living are creative pursuits. Csíkszentmihályi (1996), found in his research that "When people are asked to choose from a list the best description of how they feel when doing whatever they enjoy doing most… the answer most frequently chosen is 'designing or discovering something new'" (p. 108). He went on to conclude that "Even though personal creativity may not lead to fame and fortune, it can do something that from the individual's point of view is even more important: make day-to-day experiences more vivid, more enjoyable, more rewarding" (p. 344). In summing up their conclusions about creative endeavours Scott, Leritz, & Mumford (2004), stated that "Few attributes of human performance have as much impact on our lives, and our world, as creativity" (p. 361). In discussing beliefs and misconceptions about creativity Sawyer (2012), commented that "Creativity is a healing, life-affirming activity. This belief is supported by the research" (p. 409).

If creativity could be the factor that keeps us all alive, and figures prominently in making life worth living, it follows that we should want more of it. Yet there remains a lack of clarity around what creativity is, where it comes from, how to define it, how to assess it, whether it can be enhanced, and if it can, how to enhance it. That's a lot of uncertainty for something that some suggest is required to, literally, ensure the survival of the human race.

1.1 Overview

This dissertation proposes that creativity is best understood as an integral part of complex adaptive systems and it will present arguments to support this view. A complex adaptive system is any set of diverse, interdependent agents that interact with and adapt to each other and their environment, thereby resulting in a new, emergent entity that could not have been predicted from complete knowledge of the agents and their relationships. Complexity and complex adaptive systems will be discussed in detail in Section 2.3.

Stephen Hawking has referred to this as "the century of complexity" (Sanders, 2000), arguing that complexity science is the key to us gaining a better understanding of our universe. Complexity arises when interdependent agents interact with and adapt to each other and their environment, thereby resulting in a new, emergent entity (see section 2.3 of this dissertation for elaboration). This dissertation proposes that the creative process is an integral part of complex adaptive systems. That is, wherever there is a complex adaptive system, there is creativity, and wherever there is creativity, there is a complex adaptive system. Arguments and evidence will be presented to support this theory. Of course, precise definitions are essential to the argument. These definitions are discussed and developed throughout this dissertation. That is, simpler or more widely accepted definitions are used in the literature review. Some definitions are evolved in the articles, culminating in the final article with definitions of creativity and complexity which complement each other and support an integrated complexity of creativity framework. The reader may wish to review the glossary before proceeding further.

Recognizing the dependent relationship between complex adaptive systems and creativity can help advance the understanding of both fields. Both creativity and complexity are relatively new areas of study. As can be expected in any new field, there are no widely accepted definitions of the terms themselves (creativity and complexity), and there are many conflicting, competing theories. If we accept the possibility that the two share a dependent relationship, then areas of congruence can be viewed as self-reinforcing, while areas of incongruence can be viewed more critically. This could help advance the understanding of both fields more rapidly.

Trying to make advances in either field by putting the two together – creativity and complexity – may seem, at first glance, a bit like the blind leading the seeing impaired, through a dense forest, with landmines everywhere. But, in fact, what we know about each area exhibits so many similarities that viewing both together leads to increased clarity.

This dissertation addresses the following primary research questions:

- What support is there for understanding creativity as a characteristic of complex adaptive systems?
- What parallels are there between major characteristics of complex adaptive systems and the results of creativity research?

These questions are explored by researching the parallels between three main characteristics of complex adaptive systems and the research results of creativity and innovation. Each characteristic is explored in a separate article and each article addresses one of the following sub-questions.

- How would a complexity theory of creativity explain the paradoxes revealed in creativity research?
- In what ways does diffusion of innovation data support a new complexity perspective of creativity and innovation?
- What definition of creativity emerges from a complexity theory of creativity?

It should be noted that, due to the nature of complex adaptive systems, this dissertation necessarily sacrifices depth for breadth in some areas. While complexity theory is not anti-reductionist, it does view a reductionist approach to research as just one part of a holistic approach. This holistic approach considers the whole, the parts at each level of reduction, the interrelationships between the parts at each level, and the interrelationships between the levels (Holland, 2012). When searching for a possible complexity theory of creativity, this necessitates a broad view of the theoretical and research landscape. The search for meaningful relationships between complexity and creativity that may point the way toward a successful theory of both requires as much breadth as can be achieved in a reasonable timeframe. The current fragmentation in creativity research may, at least partially, be the result of applying a reductionist view to studying a topic that needs a holistic view. For example, a great deal of research has gone into looking for personality factors related to creativity. Eysenck (1995), has called this research a disappoint, yet he goes further by theorizing biological correlates of the personality factors that he has agreed do not correlate well with creativity. Complex adaptive systems theory suggests that creativity has more to do with relationships than some individual biological factors or personality traits.

This is an articles-based dissertation. As such, it consists of an introductory chapter, and a literature review, followed by three articles and a closing chapter. This introductory chapter includes background on the author, his linkages to the material, and his potential biases and perspectives, with a view to helping the reader see how the material might fit within, extend, or modify, his or her own worldview. The three articles were written to stand on their own, ready to be submitted to journals for possible publication. As such, there is some repetition.

The three articles follow the literature review. They are:

The Order – Chaos Dynamic of Creativity

The Complex Adaptive Process of Innovation Diffusion

The Ontological Emergence of Creativity

The literature review covers three areas: creativity, innovation, and complexity. The research on creativity has been covered broadly, with a view to illustrating how broad the research in the field has been. This is particularly the case when it comes to theories of creativity. Since this dissertation is about developing a new theory of creativity, it is important that the breadth of existing views be covered. The research on innovation is more focused. Everett Rogers' (2003) diffusion of innovation model is covered in-depth because of its close relationship to the second paper. Related innovation theories are also addressed. Finally, complexity theory is reviewed. From an initial literature review, the most-cited authors were selected and reviewed here, resulting in a broad range of perspectives.

This dissertation concludes with a final chapter that discusses the articles as a whole and with respect to the research questions listed above. Implications of and possible directions for future research are also discussed.

For any reader who is unfamiliar with the topics of creativity or complex systems, it is advisable to keep the glossary handy (see page 349). It may even be helpful to review it before reading the literature review. For some readers, it may also be helpful to read the final chapter next.

1.2 The Author

1.2.1 Background

From my background as an engineer and an entrepreneur it may not be readily apparent how or why I would have come to the point of researching creativity and complexity, nor how I could have the requisite background. Despite an education steeped in reductionism, it is possible for a curious person to see that all of the 'truths' taught throughout a typical education do not hold up to scrutiny. Therefore, I present here a brief history of me and the complex path that has led me to the study of the complexity of creativity.

The year was 1984, I had just finished my engineering degree a few months earlier, and I was certain I never wanted to read another non-fiction book. Then I saw the PBS series *The Brain*, and I was hooked. I immediately went out and bought the companion book by Richard Restak (1984) and devoured it. It sparked an interest in me, and a desire, that has never died. I am fascinated by the brain, the mind, how and why we do the things that we do, and how we can influence those things and become better. Better in whatever way we choose.

I was older than the average engineering graduate. My non-conformist ways had resulted in me not making it to the end of high school. I never had a problem passing exams, even though I seldom studied, didn't pay attention, skipped a lot of classes, and missed more classes due to suspensions. No, I had a problem with the constricting feel of the conformist straitjacket society was trying to wrap me up in. And I didn't see the point of struggling through what seemed, at the time, to be an artificial reality. I didn't care if I had to dig ditches for the rest of my life to earn a living. So, what did I need high school for?

Even during my teenage years, as I struggled with meaningless days, weeks, and years of high school, I had a trade. Since the age of 13, I had been working for my father as a camera repair technician. And I was very good at it. But around the time I was being asked not to return to my high school (well, told not to return), I had also reached a point where I knew I wasn't going to work for my father any longer. So – ditch digging it was…

It wasn't long before the harsh realities of life caught up with me. Ditches were dug with backhoes, operated by people who not only finished high school but went on to take specialty training in heavy equipment operation. And the truly-manual-labour jobs went to guys in their thirties who were married and had kids to support. (Please note there is no gender bias intended in my writing – the fact that women didn't get jobs as manual labourers was just another harsh reality of the otherwise-amazing ‘70s.) So, I entered community college as a ‘mature’ student at the age of 19, and I went back to working for my father to support myself. I worked on the same straight-commission basis that he offered any other employee and made very good money.

A couple of years later I was a mechanical engineering design technician. At my first job – designing distribution transformers for Westinghouse – I worked in a department with two design technicians who were only a few years away from retirement. They had started working at those jobs just after the Second World War! They provided me with a glimpse of my potential future and I felt the straightjacket of societal norms and expectations cinching up around me again. A quick survey of the company I worked for revealed that supervisors, managers, and those with more interesting jobs, were all professional engineers. Surprisingly, it looked like my ticket to more freedom would come in the form of higher education.

When I considered going back to school for an engineering degree, I found out that I could get credit for the first year if I had a three-year technologist diploma. So, in order to upgrade my diploma, I managed to cram eight months of full-time school into twelve months of part-time study, while I worked at my full-time job.

By this time, I was married and expecting my first child. So, when the assistant dean told me – after all my hard work – that they no longer gave technologists credit for the first year of university, I was angry and frustrated. I had already been accepted into the Engineering Program at the University of Western Ontario, and classes were starting in a few days. But I was mentally and emotionally prepared for three years of school, not four (financially I wasn’t prepared at all, but we learned to be frugal – very frugal). I looked into the appeal process and wrote an impassioned letter to the university’s Senate. Surprisingly enough, my appeal was successful and on the first day of classes, I was scrambling to change all my first-year courses to second-year courses[3]. A few short, intense years later, I was living and working at Honeywell in Toronto, and falling in love with *The Brain*.

By 1985, opportunity beckoned and I moved my family from Ontario to New Brunswick to take my first supervisory job. At the age of 27, I was supervising technicians and engineers who ranged in age from 28 to 62. Inexperienced as I was in the area of supervision, my extracurricular reading necessarily changed from the brain and psychology to the *Harvard Business Review*. However, even there I found myself gravitating toward the psychological side of business, particularly the topic of motivation.

I discovered that I loved supervision and management, primarily because of the intricacies, nuances, and complexity of the leadership role. And the job was fantastic. I was responsible for all processes and technical support for the manufacturing operations involved in producing nuclear fuel bundles at the Combustion Engineering facility in Moncton. Unfortunately, after only a year at this job, the plant was scheduled to be closed. I had no luck finding another supervisory or management position, so I took a job in Dartmouth as a manufacturing engineer at Hermes Electronics, manufacturing sonobuoys. It felt like a step backward to me, so I decided to prepare for my GMAT and get an MBA, so I could get back on the management track.

I was pleased with my 98th percentile ranking in the GMAT (and quite surprised… who knew? certainly not me, at the time), but it made little difference to me. I had a full-time job, and a wife and three kids to support, so I had to choose a school based on proximity.

---

[3] At the time I knew nothing about the relationship between non-traditional educational experience and creativity (Adams, 2005). Even now I don't know if my circuitous route was non-traditional enough to influence my creative abilities, but it is an interesting relationship to consider.

While it didn't seem like it at the time, as I reflect back on those days, some were pretty challenging; standing at a cold bus stop at 7am to get to work, walking to the ferry terminal after work to get to Halifax, only to hop another bus to get to class, eating supper along the way. After class, I would take another bus to the transfer station in Dartmouth where my wife would pick me up, with our three little ones asleep in the back seat (by that time it was too late to get the last bus to Cole Harbour where we lived). But it was only two days a week, for eight months of the year – just another minor first-world problem.

After a couple of years, I got a promotion to the position of production manager. I was one of two production managers responsible for the operation of a factory with a workforce of 500. I was the youngest production manager the company ever had, but the extra work did mean that I had to put the business venture I had started on hold. On the other hand, my interest in motivation was rekindled. Wherever possible I studied the field as part of my MBA and I applied the theories every chance I got. Seeing absenteeism rates go down and production figures go up just from treating people like people, rather than like numbers or machines, was wonderful; linking it to my studies made it like being in a living lab.

Fast forward to 1993 (skipping over a couple of years as a production manager for a high-volume consumer goods company, and a couple of years as the mechanical engineering manager at a consulting organization). I made the jump from the sinking ship of the North American manufacturing industry to the rising star of IT; in particular the nascent field of eLearning – or what was called Computer Based Learning (CBT) at the time. I was working for a brand-new Fredericton-based subsidiary of a company headquartered in BC. After less than a month of working as a lowly project administrator, I was asked to take on the supervision and management of the software development, IT, graphics, and quality assurance departments. All of those departments together consisted of a total of seven employees at the time, but that was half the company, and my project management duties had me closely involved with the other half of the company as well as the development departments of the parent company in BC and Alberta.

The company was tiny compared to what I was used to. That in itself was an exciting change for me. But what got me most excited was the creativity! The creativity that I was a part of – creativity that I was leading. We were breaking new ground, and we were growing – quickly.

After a few years, the typical frustrations of being a subsidiary – with a head office syphoning off resources – set in. So, I suggested to my boss that we do a leveraged management buyout. I recall saying to him: "I'm not sure exactly what a leveraged management buyout is, or how you do one, but it sounds like what we should be doing." Not a very convincing argument apparently. He declined. He declined the second time I suggested it too. But we eventually got there. We learned what a leveraged management buyout was by doing it. I did lots of research at the library to learn about financing, valuation and writing business plans. I used several books as references to come up with the first version of our business plan, which received accolades from most of the people we talked to.

We called the company LearnStream, and a few short years later we were flying high. We were not just one of the darlings of the New Brunswick business community, we were recognized internationally as a major player in the eLearning industry. We had become the largest custom courseware developer in North America. Multi-million-dollar deals were becoming almost commonplace. We had over 160 employees and we were always looking for new people to join our team.

To ride the wave even higher we raised money by selling an equity share to our largest customer. Fortunately, my partner and I sold some of our own equity as part of the deal, because a short time later, in the fall of 2001, the IT industry went into a tailspin. The ride down was even faster than the ride up – and certainly a lot more painful. And there seemed to be no more room for creativity in the industry. Any companies that wanted us to develop eLearning only wanted to pay for very low-end, uninspired products – text on a screen with a few graphics. Stuff that should have just been published as a textbook, or a pdf. The excitement of leveraging the interactive abilities of computers to really teach was largely gone. I wasn't learning anything new myself, I was tired of having to lay off people who had become my friends, and I was becoming miserable. I left the company in 2003 and we sold it a year later for little more than enough to cover outstanding loans.

After that, it took me a few years to find something I could be passionate about. I took a few years off – filling my time with exercise, trying to learn guitar, piano, and languages, travelling, and investing in possible business startups. Then, as I was forced to recall what it's like to be broke, I started working with another startup company as an equity partner. We developed some web-based games for adult education and a series of textbooks on international trade. After a couple of years, the company imploded, largely due to personality clashes. Following that I worked for another e-learning company, I did some management, business development and market research consulting and I developed a course called *Data-Driven Decision Making* for UNB Online.

However, following my years at LearnStream, nothing grabbed my attention and held it. Nothing sparked my passion. Nothing, until I decided to pursue a doctoral degree related to creativity. It began when I was introduced to Dr Dhirendra Shukla by my former LearnStream business partner. My conversations with Dr Shukla – and subsequently Dr Rob

Austin – led me to the idea of an interdisciplinary PhD in the area of creativity. However, I still wasn't back to a firm financial footing, so I knew this was going to have to be another part-time endeavour. I started working for Dr Shukla in November 2012, as the Program Coordinator for the Technology Management and Entrepreneurship program at the J. Herbert Smith Centre in UNB's faculty of engineering. The following January I started teaching a new course *TME1001 Introduction to Technology Management and Entrepreneurship: Create Creativity*. It was a great experience that allowed me to dip my toe into the waters of the academic field of creativity and confirm that was the route I wanted to take.

What does all of the preceding history have to do with this dissertation or my connection to the subject matter?

1. Working as a repair person may be one of the best ways to learn about design. You quickly learn that some makes and models are easy to work on, while others are almost impossible. Every design choice is governed by – or should be – end-user needs (form, fit and function), aesthetics, ease of assembly, ease of repair, price, durability, and total operating cost. These various features often relate to each other in complex ways.
2. I applied the principles listed above as a design technician.
3. Most of my time as a manufacturing engineer was spent in creative endeavors, problem-solving and designing one-off pieces of equipment – including early robotics and automation equipment.
4. Creative problem solving is one of the mainstays of the engineer and the entrepreneur.
5. Product design, production lines, and the social systems of a business organization are ideal areas to see complexity at work first-hand; where the

creative solution to one problem can result in a myriad of unintended consequences – both good and bad.

6. As a manufacturing engineer, production manager, and as a business owner, I learned about the complexities of business and, even more so, the complexities of dealing with people.
7. At LearnStream, the majority of our workforce consisted of instructional designers, media artists, and programmers. I was always fascinated by how each group was creative, in different ways, but also in similar ways. However, the most creative ideas frequently came when people from each of those groups – people who often seemed like they spoke different languages – worked together in interdisciplinary teams. It was also readily apparent how being a typical 'boss' could kill creativity, while being a leader who could set aside the leadership role could enhance it.
8. There is a lot of uncertainty when dealing with creativity and when dealing with complex systems – there is seldom one right answer and recommended approaches are mostly anecdotal or based on opinion.

When I started teaching *TME1001 Introduction to Technology Management and Entrepreneurship: Create Creativity,* I thought my PhD research would be something along the lines of: teach a class in creativity; give the students a creativity test and task-motivation assessment at the beginning of the year and at the end of the year; analyze the numbers and, hopefully, report that those students who displayed more intrinsic motivation showed a greater increase in creative ability. In fact, I was even able to gather preliminary evidence, from teaching that first course, that the course was able to raise the average students' score on a Torrance Test of Creative Thinking by over 16%. Simple, right? In fact, it was too simple. As I progressed in researching the topic, I realized that there are many different definitions of creativity, different ways of viewing creativity, different ways of testing creativity, and all of them suspect. How can you possibly expect to test creative ability by asking someone to sit down at a specific time and place and complete a *test*!? A test where the participant has little-to-no choice in how they express their creativity.

While I was writing the final paper for the first course in my PhD program, I was grappling with how to describe what I felt, by then, was the multifaceted nature of creativity. I had written in the paper about how creativity theories have seen a progression over the years, going from process-based (stage theories) to cognitive/developmental, to psychometric/personality to social to componential to the systems perspective. I was trying to express how the nature of creativity went beyond any of the theories of creativity that I studied; that creativity theories needed to continue their evolution and go further than the systems perspective that Csíkszentmihályi had written about (Csikszentmihalyi, 1996). At first, I was thinking creativity could be compared to a syndrome. This led me to thinking of it as 'a complex' (in medicine, syndrome and complex often go together). I wasn't thinking of creativity as a medical condition, but I was trying to find an analogy that would lead me further in my thinking about creativity.[4] As I Googled terms to try to find a better way of expressing my thoughts, it didn't take long before I came across complexity theory. Even with just a little light reading on the subject, the concepts of complexity theory grabbed hold of me and would not let go. I briefly mentioned complexity theory in that final paper of my first course, and it has played a role in every paper I've written since.

---

[4] Medical definition of complex: "having many varied interrelated parts, patterns, or elements and consequently hard to understand" ("Complex," 2016).

Not long after that first course, I read Stacey's 1996 book *Complexity and Creativity in Organizations* (Stacey, 1996). The concepts I read there helped me make more sense of a lifetime of experiences; particularly my experiences in business and creative endeavours. But it wasn't until I finished reading Kaufman's *At Home in the Universe* (S. A. Kauffman, 1995), along with more from Stacey, Morçöl, Mitchell, Bak, Morin, Sawyer, and Holland (Bak, 1996; Holland, 2014; Mitchell, 2009; Morçöl, 2012; Sawyer, 2005; Stacey & Griffin, 2005; Stacey, 1995 Stacey, 2007; Stacey & Mowles, 2016), that I was beginning to feel like I knew enough to express how I think creativity and complexity fit together. Not only has complexity theory come to colour my interpretation of all aspects of creativity, and pretty much everything else, I have come to see creativity and complexity as intimately linked. This dissertation will explore that relationship, as I look for evidence to support my intuition and as I search for a model that could show the relationship between complexity and creativity.

1.2.2 Epistemology

Having some understanding of my epistemology and biases should help the reader interpret the meaning and intent of the work contained in this document (Hammer & Elby, 2002; Takacs, 2003). Additionally, the exercise of trying to thoughtfully shed light on my epistemology and biases is intended to help me critique my own work, identify shortcomings, and, hopefully, enable me to view this work from perspectives other than my own. In the words of Morin (2002), "Complex knowing… demands a self-observing (and, I would add, self-criticizing) turn on the part of the observer-conceiver" (p. 334).

So, let's begin with a quick summary. I'm convinced creativity should be viewed as an integral characteristic of complex adaptive systems. I'm further convinced that complex adaptive systems are creative systems. I'm a non-reductionist (to an extent – see below for elaboration). I'm largely a post-disciplinarian (but I believe it would be counterproductive if everyone was). When it comes to a fixed versus growth mindset, I am firmly on the side of growth (in fact, I have some difficulty understanding those who think that an individual's capabilities in areas such as creativity are fixed). When it comes to the *locus of control*, mine is more internal than external, but this needs to be interpreted from a complexity perspective.[5] My epistemology is coloured by many understandings, but it culminates in an epistemology of complexity.

Digging a little deeper: if you take Werner Heisenberg's (Heisenberg, Eckart, & Hoyt, 1930) uncertainty principle (the more precisely the position of an object is known, the less precisely its momentum can be known), plus Karl Popper's philosophy that theories and hypothesis cannot be proven (Popper & Bartley, 1982), they can only be disproven, along with Thomas Kuhn's (1970) explanation of paradigm shifts,[6] and Edgar Morin's (2002) epistemology of complexity (see next section), then you have a pretty good outline of my views on epistemology. Of course, each of these topics is complex. To mention four such large, complex, and important topics in one paragraph certainly does not do them justice. I wish it were possible to discuss each in depth, but the intention here is merely to give the reader a small glimpse into what shapes my thinking, to possibly reveal potential biases. On the other hand, in order to give a fair glimpse, I will have to elaborate on my views regarding Popper.

---

[5] Sensitive dependence on initial conditions suggests an inability to predict the longer-term consequences and outcomes of one's own actions.

[6] Which, incidentally, may well occur in a manner consistent with self-organized criticality theory (see the complexity literature review section for an explanation of self-organized criticality).

I believe Popper's philosophy regarding falsification was an important milestone. However, despite his protestations to the contrary (see Thornton, 2018, section 9) Popper's *falsification* is based in positivism. The more nuanced view that I subscribe to (when combined with the other philosophies mentioned in the previous paragraph) is well represented in *Science: Key Concepts in Philosophy* (French, 2007), which could be distilled down to, 'it's complicated.'

Additionally, in the natural sciences, I lean toward pragmatism while in other sciences, I lean toward social constructivism – to the degree that both are consistent with the previous paragraphs. However, I also recognize an element of social constructionism in the natural sciences, in the sense of Thomas Kuhn's (1970) paradigm shifts: as Morin (2002) points out – when we are in a paradigm, we can't see it as such.

In my own words, rather than appealing to the vast literature in this area: as a pragmatist, I believe there are different levels of *truth* that exist in our universe. There are definitional truths, which symbology (semiotics, languages, etc.) is built upon – truth here is the truth because we define it as such. There is the truth of logic and math which, while it can get complicated, is black and white – we recognize an immutable truth when we find it. There are also individual truths (what we each believe to be true), societal truths (that which the majority of a society holds to be true), and absolute truths. Individual and societal truths are mutable – they change as we learn more about our universe and ourselves. On the other hand, I believe whatever absolute truths there may are unknowable.

First and foremost, my epistemology is that of complexity. It is an epistemology informed by the theoretical perspective of complexity.

1.2.2.1 *Epistemology of Complexity*

A complex system can only be understood by understanding its components and their "simultaneously dynamic and systematic inter-relationships" (Walby, 2003, p. 3). Holism, in this sense, means the whole, the parts, and all the interrelationships (part-to-parts, part-to-whole, and whole to parts). This is what is behind my earlier comment that I am a non-reductionist, but only to a certain extent. Reductionism can still help us understand the parts, but any learning that results must be brought back into the system – the whole and the interrelationships.

Sensitive dependence on initial conditions suggests that our ability to predict the future behaviour of a system decreases with time and is dependent on our knowledge of the history of the system (path dependence). It also means that even if we live in a clockwork universe, we will never be able to measure everything accurately enough to be able to make accurate, specific predictions. We can suggest probabilities and predict patterns, but that is the extent of what our 'knowledge' permits us. Another way of looking at this is that the maximum efficacy of an action will always be immediately following the action. While the ultimate consequences of our actions may not be foreseeable, the immediate consequences are more amenable to prediction (Morin, 2002). Furthermore, complex systems are contextual, so generalizability is limited. That is, if a 'system'[7] is replicated in a different time and place, it may react differently because it is embedded in a different context.

---

[7] 'System' is enclosed in quotation marks because there are no truly closed systems (or isolated systems – to use, more precisely, the language of physics). Therefore, the boundary of any system may be seen as somewhat arbitrary. If the hypothesis of a multiverse, which arises out of string theory, is correct, then even our universe may not be an isolated system, it is merely a convenience to think of it as being bounded.

In *The Epistemology of Complexity*, Morin (2002), sums up what it means to think when one adheres to an epistemology of complexity:

> Complex thinking is not omniscient thinking. It is, on the contrary, a thinking that knows it is always local, situated in a given time and place. Neither is it a complete thinking, for it knows in advance that there is always uncertainty. By the same token, it avoids the arrogant dogmatism that rules noncomplex forms of thinking. Complex thinking, however, does not lead to a resigned scepticism, because, by completely breaking with the dogmatism of certainty, it throws itself courageously into the adventure of uncertain thinking and participates in the uncertain adventure upon which, from its birth, humanity has been embarked. We must learn to live with uncertainty rather than do what we have been taught to do for millennia and seek, through whatever means, to avoid it. (p. 339)

Following Morin (2002), you could call those who adhere to this epistemology of complexity co-constructivists, that is, "we construct our perception of the world, but with the help of the world itself" (p. 332). Morin goes on to explain that:

> Niels Bohr and the representatives of the so called Copenhagen interpretation of Quantum Mechanics thought that what we know is not the world itself, but the world along with our knowledge of it. We cannot isolate the world from our structures of knowing. Mind and world are inseparable. This is particularly true of the human world. Sociology and anthropology can no longer claim to be 'scientific' by the mere fact of analyzing questionnaires. It is evident that the observer must analyze itself while observing others. (p. 333)

It has been my experience that consistently applying this philosophy to one's thinking takes effort and diligence. Throughout our lives, we have all been immersed in a worldview that is heavily influenced by a Newtonian, mechanistic, positivist epistemology (Barseghyan, Overgaard, & Rupik, 2018). Four hundred years of Newtonianism is a lot of inertia to escape from, but I'm confident that complexity is the correct path for making that escape and I hope that this dissertation will help convince the reader of the value of a complexity worldview.

2 Literature Review

In order to develop a complexity theory of creativity and innovation, it is important to be aware of the current understanding of complexity theory, the current state of creativity and innovation research, how the concept of creativity has developed over the years, and how creativity and innovation relate to each other. This literature review covers three areas: creativity, innovation, and complexity. Creativity is covered broadly, with a view to illustrating how broad the research in the field has been. This is particularly the case when it comes to theories of creativity. The literature on defining creativity is also covered since any theory of creativity must be related to a definition of creativity. The literature on assessment and enhancement of creativity is reviewed, since these topics may benefit from a clear definition and theory. The literature review on innovation is more focused. Everett Rogers' (2003) diffusion of innovation model is covered in-depth because of its close relationship to the second paper. Related innovation theories are also addressed. Finally, complexity theory is reviewed. From an initial literature review, the most-cited authors were selected and reviewed here, resulting in a broad range of perspectives.

2.1 Creativity

Creativity. Just ten letters long. Longer than the average word, but not out of the ordinary as far as word length goes. In fact, it's quite small – minuscule even – in relation to what it represents. Creativity, as a field of study, is… well, - it's freakin' huge!

As this dissertation will show, creativity is a fascinatingly complex, broad, poorly understood, and poorly defined area of research. It has been researched and written about from many points of view, including psychology, education, educational psychology, business, marketing, human resource management and development, arts, entrepreneurship, math, history, manufacturing, textiles, engineering, neuroscience, problem-solving, and philosophy. Some would argue that creativity can only be understood with respect to a single domain at a time, that is, creativity is domain-specific (Baer, 1998), while others argue that the skills, abilities, and traits associated with creativity are the same and are transferable across domains (domain-general) (Plucker & Beghetto, 2004). The current consensus seems to be that creativity likely occupies a middle ground, being partially domain specific and partly domain general (Baer, 2010).

While the multiple-discipline approach to creativity research has likely contributed to some of the fragmentation of the field, this author anticipates that a post-disciplinary view may result in a more unifying framework. The one area of creativity to spark more debate than that of the domain-specific versus domain-general debate is the definition of creativity. So, this creativity literature review will start there.

2.1.1 Definition.

The modern era of creativity research is often said to have begun with J.P. Guilford's Address of the President of the American Psychological Association at Pennsylvania State College on September 5, 1950, (Guilford, 1950) when he noted that "The neglect of this subject [creativity] by psychologists is appalling" (p. 445). At the time, Guilford danced around the definition of creativity:

> In its narrow sense, creativity refers to the abilities that are most characteristic of creative people. Creative abilities determine whether the individual has the power to exhibit creative behaviour to a noteworthy degree. Whether or not the individual who has the requisite abilities will actually produce results of a creative nature will depend upon his motivational and temperamental traits. To the psychologist, the

> problem is as broad as the qualities that contribute significantly to creative productivity. In other words, the psychologist's problem is that of creative personality… Creative personality is then a matter of those patterns of traits that are characteristic of creative persons. A creative pattern is manifest in creative behavior, which includes such activities as inventing, designing, contriving, composing, and planning. People who exhibit these types of behavior to a marked degree are recognized as being creative. (Guilford, 1950, p. 444)

Not only did Guilford fail to define creativity, but the number of circular definitions he used is also dizzying. This quote also illustrates that the approach to creativity research at the time was to find people who were considered unquestionably creative – people who had achieved eminence – determine their personality traits, discover which traits they seemed to share most often, and look for those traits in others as a possible predictor of creative ability. This approach necessarily focuses on traits associated with creative results, which may not be the same as those associated with creative potential.

It has been reported by Parkhurst (1999) that in 1960, Repucci counted between 50 and 60 definitions of creativity in the literature. Shortly after, Rhodes (1961) wrote that "In time I had collected forty definitions of creativity and sixteen of imagination. The profusion was enough to give one the impression that creativity is a province for pseudo-intellectuals" (p. 306). By 1980, Welsch concluded, "the literature contains such a variance of definitional statements that the task of defining the concept of creativity is a challenging one" (Welsch, 1980, p.3). Welsch went on to propose that this was largely due to the many different frames of reference of creativity researchers; from psychologists to artists and inventors, educators and social scientists. She also noted that "A comprehensive view is rare" (p. 3).

In 2010 Hennessey and Amabile saw that things were not getting better: "Criteria for assessing persons or products may appear to be straightforward after decades of research. But appearances deceive. Debates surrounding definition and measurement continue to loom large" (Hennessey & Amabile, 2010, p. 572).

While most creativity researchers agree that the standard definition of creativity requires both uniqueness and usefulness or appropriateness (or one of a number of synonyms) (Plucker, Beghetto, & Dow, 2004), this definition leaves open to question the definition of the terms uniqueness, usefulness and appropriateness. It also does not address the question of who is to judge uniqueness, usefulness, or appropriateness, or how creative works should be judged in these areas (Runco & Jaeger, 2012).

Many creativity researchers differentiate levels of creativity by categorizing people or their creative products as either Big C or little c (Kozbelt, Beghetto, & Runco, 2010). Big C creativity is novel in a worldwide and historical context, has a lasting impact, and may result in a paradigm shift. Little c creativity is also called personal, or everyday, creativity. The little c product or idea is only novel from a personal point of view, and the product or idea generally does not have an impact beyond the individual and his or her immediate surroundings. Kaufman and Beghetto (2009) have extended this classification with the addition of 'Pro c' and a 'mini c' classifications.

But creativity is not a dichotomy, being either big or little – any more than it has three states – none, a little bit (little c), or a lot (Big C), or four (Big C, little c, pro c and mini c). There is a wide range of creativity unaccounted for between these discrete states. Creativity exists on a continuum (Amabile, 1996). If creativity was to be assigned an absolute scale from 0 to 100, 0 might represent the creativity of a rock, while 100 might represent the creativity of the primordial intelligence (or whatever conception of 'god' one may have… or whatever next-best concept of the ultimate creative force one's less-than-100-on-this-creativity-scale creative brain can come up with) and creative theorists could spend countless hours discussing exactly where the likes of Michelangelo, Da Vinci, and Einstein should fall on this scale – or, for that matter, where Big C, little c, pro c, and mini c should land on this ultimate creativity scale. But this paper was written with more practical matters in mind. I agree with Amabile's definition of creativity:

> A product or response is creative to the extent that appropriate observers independently agree it is creative. Appropriate observers are those familiar with the domain in which the product was created or the response articulated. Thus, creativity can be regarded as the quality of products or responses judged to be creative by appropriate observers, and it can also be regarded as the process by which something so judged is produced. (Amabile, 1996, p. 33)

Yet, there is also value in Plucker, Beghetto, and Dow's (2004) definition, which identifies social context as an important aspect of creativity: "Creativity is the interaction among aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context" (Plucker et al., 2004, p. 90). However, this dissertation will begin by employing what is often referred to as the standard definition of creativity (Runco & Jaeger, 2012), that is, creativity is the generation of something which is original, and of value or adaptive. In the third article, an alternative definition, derived from complexity theory concepts, will be proposed.

It should be clear that if a definition of creativity cannot be agreed on, it makes it challenging to assess creativity. And if you can't assess creativity, how can you determine if a four-hour seminar on parallel thinking, or a year-long course covering meta-cognition and creative problem solving, along with other cognitive techniques and real-world exercises, do what they claim to do: enhance creativity?!

2.1.2 History

2.1.2.1 Prehistoric to 18th Century

Early stone tools are the beginnings of our archaeologically-known, ancestral legacy of creativity (Pagel, 2012). The oldest known stone tools were found at two sites near the Kada Gona River in Ethiopia and are estimated to be 2.6 million years old. These stone choppers were crudely flaked on one end. However, bones with cut marks on them, found near Dikika, Ethiopia, indicate that these stone choppers likely existed as long as 3.4 million years ago (mya) (Pringle, 2013).

Creative progress was slow for our ancestors; it took over 2.5 million years for the crude stone chopper to evolve into a well-crafted bifacial stone tool (3.4 mya until 1.76 mya). These ancestors of ours seem to have taken another three-quarters of a million years to start using controlled fire (1 mya) and another half a million years before hafting was used to create composite tools (Larick & Ciochon, 1996; Pringle, 2013; “Hafting,” 2016). Then, a long, slow acceleration of creativity began. 200,000 years ago Neanderthals developed a glue from birch bark tar for hafting (Vergano, 2014) and 77,000 years ago they were using leaves from a tree containing natural insecticides and larvicides for bedding. Archaeologist Lyn Wadley’s analysis suggests that the inhabitants of Sibudu's cave, some 70,000 years ago, were likely "competent chemists, alchemists and pyrotechnologists" (Pringle, 2013, p. 41).

About 40,000 years ago, the first known cave paintings were created. The oldest known being a 40,800-year-old red disk located in El Castillo, in northern Spain. The next oldest known paintings are of hands and animals. They were found in a series of seven limestone caves on the Indonesian island of Sulawesi. They were just discovered in 2014, and are estimated to be at least 39,900 years old (Wilford, 2014). Prior to this recent discovery, the oldest know figurative paintings were the 32-36,000-year-old Chauvet-Pont d'Arc Cave images, discovered in 1994. However, for over half a century the Lascaux Cave paintings, discovered in 1940 and estimated to be about 17,300 years old, were thought to be the oldest cave paintings (Jabar, 2014; Pagel, 2012; "Cave painting," 2016). Stylistically, the Chauvet and Lascaux paintings are very similar, even though there were over 13,000 years separating their creation - as Pagel (2012) points out, a period about three times as long as all of recorded history. In an age when technologies and styles can seem very short-lived, transient even, it's hard to imagine living in a world where technologies and styles can last for many millennia.

It appears that this slow but accelerating progress may have been the result of social learning, a capacity that appears to have set our ancestors - from Homo habilis to early homo sapiens - apart from all other animal species. This has recently been illustrated by Lewis Dean and his colleagues at St. Andrews University. Dean gave children, chimpanzees and capuchin monkeys a multi-level puzzle that resulted in increasing levels of reward. After 30 hours, less than ten percent of the chimpanzees made it to level two, and only one made it to level three - the highest level. The capuchin monkeys fared even worse, with only five percent reaching level two, and none making it to the highest level. After just three hours, over half the human children reached level two, and just under half reached the highest level. Dean's theory is that the children outperformed the other animals due to their tendency to teach, imitate, share, and communicate with each other. All of these traits are found in other animals but to a lesser extent (Dean, Kendal, Schapiro, Thierry, & Laland, 2012).

The evolutionary step that helped us out-imitate and out-learn other primates might have been the development of mirror neurons (Pagel, 2012). A mirror neuron fires in the same way when we watch an action performed as it does when we perform the action ourselves. Mirror neurons have been implicated not just in learning through imitation, but in communication, the theory of mind, and empathy ("Mirror neuron," 2016), a trait that has itself been shown to be an essential ingredient for creativity (Carlozzi, Bull, Eells, & Hurlbut, 1995).

According to Simonton (2004), through the ages, three historical conceptions of creativity stand out from the diversity of thought on the subject: divinity, madness, and craft. From ancient historical times until the time of Classical Greece, the act of creation was seen as being only within the purview of the gods, while simple mortals merely followed rules to recreate or imitate (Plato, n.d.; Simonton, 2004; "History of the concept of creativity," 2016). "And the painter too is, as I conceive, just such another --a creator of appearances, is he not? And the tragic poet is an imitator, and therefore, like all other imitators, he is thrice removed from the king and from the truth?" (Plato, n.d.).

Plato refers to both poets and painters as thrice removed from truth because they merely imitate the work of 'artists', those we would call craftspersons today.

> "Then the imitator, I said, is a long way off the truth, and can do all things because he lightly touches on a small part of them, and that part an image. For example: A painter will paint a cobbler, carpenter, or any other artist, though he knows nothing of their arts; and, if he is a good artist [painter?], he may deceive children or simple persons, when he shows them his picture of a carpenter from a distance, and they will fancy that they are looking at a real carpenter." (Plato, n.d., p. 251)

There were, of course, differing views. Aristotle saw poetry as a special case, claiming it to be that "which is neither true nor false" (Tatarkiewicz, 2011, p. 245-6).

It was during the time of Aristotle and Plato that what we now view as creativity became associated with madness (Runco & Albert, 2010), a view that was rekindled during the Renaissance and continues, at least to some degree, to this day ("History of the concept of creativity," 2016). Another concept related to creativity that had its beginnings in ancient Greece and continues to inform our current culture is that of a muse. Its origin is the Greek myth that Zeus fathered nine daughters who guided and inspired mortal 'creators' in nine separate areas: heroic or epic poetry, lyric and love poetry, sacred poetry, tragedy, comedy, music, dance, astronomy, and history (Simonton, 2001). The Christian view was similar - only God could create, humans could only make, or recreate. Sometime during the Middle Ages, individuals' exceptional talents or abilities began to be viewed as channelling an outside spirit (Runco & Albert, 2010), essentially a muse with a Christian connection.

The scientific method ushered in a new way of looking at the world, and the people in it. It began during the Renaissance with Francis Bacon (1214-1294), leading to Nicolaus Copernicus (1473-1543,) and Galileo Galilei (1564-1642). It was, in part, this new way of viewing the world that led to a new sense of freedom and independence. The idea that individuals could imagine, think up, and create works independent of the divine, proved to be a turning point, which may have helped to usher in the early part of the Renaissance ("History of the concept of creativity," 2016).

On the other hand, Stuart Kauffman (2010) argues that we have been under a "Galilean spell" for over 350 years. He is referring to Galileo's experiments showing that "gravity accelerates all objects at the same rate, regardless of their mass or composition"

(NASA Science, 2018), as the beginning of reductionism. Kauffman is on a mission "to exorcize" this Galilean spell in order to allow complexity science to flourish.

For more on the early history of the concept of creativity, see *A History of Research on Creativity* (Albert & Runco, 1999), *Historical Conceptions of Creativity* (Dacey, 2011), and The *Concept of Creativity Prospects and Paradigms* (Sternberg & Lubart, 1999).

2.1.2.2 19th Century

In Becker's (1995) review of 19th-century creativity literature, she points out that many of the questions addressed and concepts developed in 20th-century research had their roots in the previous century. She lists the questions being addressed by 19^{th}-century authors as falling into one five themes:

"1. What is creativity?

2. Who has creativity?

3. What are the characteristics of creative people?

4. Who should benefit from creativity?

5. Can creativity be increased through conscious effort?" (p. 220).

However, a review of the literature of the time reveals that some of the most interesting discussion in the field, and that with perhaps the greatest impact on the research of today, focused on the creative process, specifically, association theory. For instance, Bethune (Bethune, 1837) discussed a "chain of association" (p. 23), as a fundamental element employed in the creative process. Decades later, in 1877, Jevons (1913) reiterated the need for associative thinking, while adding divergent and convergent thinking as essential components in the creative process:

> His associating and identifying powers must be great, that is, a strange fact must suggest to his mind whatever of like nature has previously come within his experience. His imagination must be active and bring before his mind multitudes of relations in which the unexplained facts may possibly stand with regard to each other, or to more common facts. Sure and vigorous powers of deductive reasoning must then come into play. (p. 576)

In fact, Jevons argued against the strict scientific method. Well over a century later, his writing seems prescient, given the shift from positivism to complexity theory that has been taking place and is ongoing (Mitchell, 2009).

> Hundreds of investigators may be constantly engaged in experimental inquiry; they may compile numberless notebooks full of scientific facts, and endless tables of numerical results; but, if the views of induction here maintained be true, they can never by such work alone rise to new and great discoveries. By a system of research they may work out deductively the details of a previous discovery, but to arrive at a new principle of nature is another matter… The greater the array of facts, the less is the probability that they will by any routine system of classification disclose the laws of nature they embody. Exhaustive classification in all possible orders is out of the question, because the possible orders are practically infinite in number. (p. 576-577)[8]

Jevons also introduced the concept of fluency, stating that "The man of one idea has but a single chance of truth. The fertile discoverer, on the contrary, chooses between many

---

[8] This idea of how great discoveries might arise from infinite possibilities will be reintroduced later as an element of a complexity theory of creativity.

theories... He compares time after time, and then chooses" (pp. 586-587). One hundred and eighteen years later, Linus Pauling said “If you want to have good ideas you must have many ideas. Most of them will be wrong, and what you have to learn is which ones to throw away” (Crick, 1996, para. 25).

The following section will look at how theories of creativity have evolved in the 21st and 21st centuries.

2.1.3 Theories.

This section will provide a glimpse into the breadth of points of view the concept of creativity raises. The purpose of this section is not to offer a complete and critical review of all creativity theories. Rather, the purpose is to demonstrate the complexity of the topic by reviewing enough theories to illustrate their breadth and variety. At the same time, it should be noted that none of them offer a complete explanation of creativity.

When it comes to theories of creativity, Theresa Amabile has been one of the most influential, and her summary of the state of psychological research into creativity remains valid:

> In the past, the psychological study of creativity has been hampered by the tendency of individual investigators to narrow their theoretical focus to a single concern – the distinctive personality characteristics of outstandingly creative persons, or the special cognitive abilities of creative artists and scientists, or (less frequently) the social environments that hinder or foster creativity. However sound the empirical research directed toward those single issues, this approach has led to a fragmentation within the psychology of creativity. (Amabile, 1996 p. 81)

Almost 20 years later this fragmentation has continued and has expanded beyond just psychology. The domains of neuroscience, social science, business, evolution, education, and others have added to the fray.

2.1.3.1 Personality

Guilford (1950), set the stage for the narrow focus of creativity over the three decades following his 1950 presidential address to the American Psychological Association: "the psychologist's problem is that of the creative personality" (p. 444). A great deal of the research throughout the 1950s, '60s and 70s focused on discovering the personality traits of highly creative people (Amabile, 1996), in order to determine how they differed from the rest of us, giving us traits that we could emulate in order to be more creative. The results have been mixed, with correlation coefficients being somewhat weak and inconsistent, and only a few factors standing out consistently. As Kasof (1995) explains, in relation to attribution theory, which will be discussed in a subsequent section:

> Creativity researchers have identified a number of dispositional correlates of creative behaviour, but these associations are seldom more than moderate in strength, and hence such dispositions account for only a modest percentage of the variance in the creative behaviour measured in such studies; moreover, as I argue later, some such traits may be associated with creative behaviour not because they cause creative behaviour but because they are effects of creativity or because attributional biases inflate their apparent covariance with creative behaviour. (p. 312)

Eysenck (1995) calls the attempt to relate personality attributes to outcomes such as creative behaviour a disappointment: "Clearly the creative groups are more flexible, but lower on socialization! But on the whole the CPI [California Psychological Inventory] is a disappointment; it does not disclose much in the way of personality attributes of creativity" (p. 110). However, Eysenck (1993) does build a theory of creativity based largely on personality:

> Many theories in psychology (and not only in psychology!) are fuzzy; precise quantitative theories are largely lacking. What I am doing here is multiplying the offense by linking several fuzzy theories (some more fuzzy than others) to try to throw some light on a fundamental problem in science and art and possibly other fields as well-namely, the nature of creativity and its relation to intelligence, personality, and genius. (p. 147)

Eysenck reduces intelligence to the speed of searches, coupled with a lower probability of error. He also argues that the creative person has an over-inclusive thought process as a cognitive style (essentially the associative theory discussed in the next section). Finally, Eysenck builds a case for highly creative people being high on the psychoticism continuum, while stopping short of being pathological (the creative people, that is, not Eysenck – however, I assume Eysenck stops short of being pathological as well). He reaches this conclusion based on the argument that over-inclusive thought processes are likely to "have affinities with schizophrenia or generally psychotic disorders but to fall short of actual psychiatric disease" (Eysenck, 1993, p. 147).

Sawyer's (2012) review of the literature indicated that creative individuals tend to be: of above average intelligence, open to experience, more impulsive, flexible, tolerant of ambiguity, attracted to ambiguity, willing to take risks, and they display: metaphorical thinking, internal visualization of problems, independence, broad interests, perseverance, independence of judgment, autonomy, and self-control. Sawyer also notes that many studies found the ability to recognize a good problem in the individual's domain is an important characteristic of creative people.

Of course, there have been many attempts to measure the creative personality with psychometrics. Two popular ones include the Myers-Briggs Personality Type Indicator Creativity Index (MBTI-CI) (Harrison, 1981) and the Keirsey temperament indicator (Keirsey, 2019). However, not everyone agrees that using psychometrics to understanding creativity is effective (for an extensive discussion of the pros and cons of psychometric testing see Emre, 2018). In a review of psychometric techniques for the study of creativity, Plucker and Renzulli (1999) noted: "practically all current work on creativity is based upon methodologies that either are psychometric in nature or were developed in response to perceived weaknesses…" (p. 35). They concluded that the development of systems thinking in creativity research makes "psychometric analysis of creativity within a sole area… less defensible than in previous eras" (p. 50).

2.1.3.2 Associative Theory

Mednick's associative theory of the creative process (1962) suggests that creative thinking is the process of "forming of associative elements into new combinations which either meet specified requirements or are in some way useful" (p. 221). That is, a creative solution comes about when two ideas are combined in a new way. Mednick saw three ways for this association to take place: through serendipity, similarity, and mediation.

Serendipity is the linking of ideas that comes about through the appearance of stimuli – usually by accident – that causes an association between two previously unassociated ideas. The discovery of penicillin by Fleming is an often-cited case of serendipity. Fleming was growing staphylococci on culture plates as part of his research on the influenza virus. After forgetting to sterilize his plates, and leaving the windows open while on vacation, Fleming returned after two weeks to find mould growing on several of the plates. Where the mould was growing, the growth of the staphylococci was inhibited. Fleming's lax laboratory procedures and his curiosity helped lead to the discovery of penicillin. The invention of items as diverse as X-Rays, the microwave oven, vulcanized rubber, and the Slinky can be attributed to serendipity (Roberts, 1989). Of course, serendipity alone cannot account for each of these discovers. Creativity, discovery and innovation are more complicated than that, as argued by many scholars (for example, André, Schraefel, Teevan, & Dumais, 2009). Serendipity requires a prepared mind if it is to lead to a creative outcome. Knowledge, curiosity and a desire to discover something new work together to prepare the mind to capitalize on serendipitous events.

Similarity is the case when associative elements are brought together because they are contiguous – in an associative hierarchy – in some way, such as through alliteration or rhyming in written work, or through the use and application of styles and norms in painting or musical composition. In product development, the associative element of similarity would most often be related to incremental improvement.

Finally, mediation is the case when a third element provides an associative bridge between two other elements that may not have otherwise become associated, if not for the mediation of the third element. Burrs stuck to the fur of Georges de Mestral's dog proved to be the mediator that brought together the idea of the zipper, and the idea of a simpler fastener (obviously serendipity plays a role in this example as well). For more examples of biologically-based mediation, see *Biomimetics: its practice and theory* (Vincent, Bogatyreva, Bogatyrev, Bowyer, & Pahl, 2006).

In Mednick's theory, people vary in their associative hierarchies. Those with steep hierarchies will give few responses to a stimulus such as 'how many uses can you come up with for a paper clip?' This is seen in word association tests as well, where people with a flat associative hierarchy – hypothesized to be more creative people – will come up with word associations that are less frequently associated with the stimulus (remotely associated) (Sternberg & Lubart, 1999).

Mednick went on to develop the Remote Associates Test (RAT), intended as a test for creative potential. It is a test that provides three words and asks the participant to come up with a fourth word related to all three. Varying degrees of remote association are required to come up with the solution to the various sets of words.

Russ and Dillon (2011) note that the associative theory resulted in the general acceptance that creativity is at least partially dependent upon having a broad search process and they concluded that the RAT is a valid measure of some types of creative thinking.

2.1.3.3 Metacognitive

Metacognition is, literally, cognition about cognition. Since cognition can be defined as: "the attention of working memory, producing and comprehending language, learning, reasoning, problem-solving, and decision making" ("Cognition," 2013), metacognition can be thought of (pun intended :) as thinking about thinking, thinking about learning, or thinking about problem-solving. As noted by Kozbelt, Beghetto, & Runco (2010) "Metacognitive processes are also frequently tied to creative thinking" (p. 32). They go on to note that tactical thinking is metacognitive, thus most cognitive theories of creativity will have a metacognitive aspect to them.

In other words, a metacognitive theory of creativity suggests that creativity can be increased by learning and thinking about how we learn and think, particularly about how we can learn to be creative and what creative thinking entails.

2.1.3.4 Divergent Thinking

Divergent thinking is thinking in an expansive way to generate many possible answers to a question, or possible solutions to a problem. Contrasting with divergent thinking is convergent thinking; a process by which one arrives at, or at least attempts to arrive at, the one right, or best, answer. Most academic examinations and IQ tests are made up of questions that require convergent thinking (Runco, 2011). Guilford is generally credited with first distinguishing between the two styles of thinking (Runco, 2011) in his structure of intellect model. Guilford also argued that divergent thinking is a major factor in creative potential (Guilford, 1956). He reasoned that divergent thinking is a personality trait associated with creative potential, because one needs to come up with many ideas in order to come up with creative ones, and because it is often the ideas which are arrived at later that are the most creative. In other words, premature closure is detrimental to creativity (K. R. Sawyer, 2012).

Divergent thinking tests are one of the most common tests of creative potential (Runco, 1991). These tests can take many forms, such as the unusual uses test, where the test taker is asked to list as many uses as they can think of for an object, such as a brick, or a paper clip. The consequences test asks participants to list all the consequences that they can think of that might result due to a hypothetical situation, such as dolphins evolving to be able to live on land and talk to humans. Figural divergent thinking tests ask participants to complete a partially drawn picture or to use a simple shape, such as a circle, as the starting point for as many drawings as the participant can come up with.

Divergent thinking tests are typically scored for fluency, originality, and flexibility. Fluency is simply the number of ideas that the test taker comes up with, while originality is the number of ideas generated that are statistically infrequent (the cut-off used is often 5%). Flexibility is the generation of ideas that are semantically different. For example, uses for a brick which make use of the bricks weight, such as paperweight and door-stop, would be in one semantic grouping, while those that made use of its dimensions, such as holding up a piece of wood to make a bookshelf and propping up a chair that has a broken leg, would be another semantic grouping, while arts and crafts uses may be a third semantic grouping (Runco, 2011).

While divergent thinking ability may be an indicator of creative potential, it is less likely to be an indicator of creative output, since it does not take into account other required abilities such as convergent thinking and motivation (Runco & Acar, 2012).

2.1.3.5 Blind Variation and Selective Retention (BVSR)

The Blind Variation and Selective Retention (BVSR) theory posits that creative thinking is a three-step process consisting of the blind generation of ideas, or idea variations, which are subsequently subjected to a selection process with the variant that proves most useful or adaptive being retained for use or further elaboration (Campbell, 1960; Simonton, 1999). Bain (1868) and Souriau (1881) introduced the concepts which have evolved into the BVSR theory first proposed by Campbell (1960) and more recently championed by Simonton (2010; 2011) while being vigorously debated by others (Simonton, 1999;

Simonton, 2007; Gabora, 2011). The following quotes from Bain and Souriau illustrate how the seeds were sown for this theory almost 150 years ago:

> In the process of deduction . . . the same line of remark might be pursued. The mind being prepared beforehand with the principles most likely for the purpose . . . incubates in patient thought over the problem, trying and rejecting, until at last the proper elements come together in the view, and fall into their places in a fitting combination… In the case of originality in all departments, whether science, practice, or fine art, there is a point of character that is worth specifying… I mean an active turn, or a profuseness of energy, put forth in trials of all kinds on the chance of making lucky hits… Nothing less than a fanaticism of experimentation could have given birth to some of our grandest practical combinations. The great discovery of Daguerre, for example, could not have been regularly worked out by any systematic and orderly research; there was no way but to stumble upon it… The discovery is unaccountable, until we learn that the author… got deeply involved in trials and operations far removed from the beaten paths of inquiry. (Bain, 1868, pp. 609-611)

> In this case it is evident that there is no way to begin except at random... In these conditions we are reduced to dependence upon chance... The truly original mind is that which discovers problems. But here again, it does no good to speak of method, since method is the application of already existing discoveries. The discovery of a new problem can therefore only be fortuitous. Thus we see the role of logic diminish and that of chance increase as we approach closer to true invention. Chance is the first principle of invention... Methodological minds cannot help having a feeling of disdain for adventurous minds which affirm before proving and believe before

> knowing... New ideas cannot have prototypes: their appearance can only be attributed to chance… Of all of the ideas which present themselves to our mind, we note only those which have some value and can be utilized in reasoning. For every single idea of a judicious and reasonable nature which offers itself to us, what hosts of frivolous, bizarre, and absurd ideas cross our mind. (Souriau, 1881, as quoted in, Campbell, 1960, p. 385-386)

Simonton's research (1999b) has demonstrated that quantity is the best predictor of eminence, which he equates to creative genius. That is, those who become best known for their creative accomplishments are generally the most prolific, publishing many unknown papers for every one that becomes widely known. The same can be seen in the music industry, where the most eminent artists are typically the most prolific, even if the majority of their songs don't make it to the top ten.

Campbell's (1960) view of BVSR is that it is fundamental to all increases in knowledge and that processes that allow shortcuts are based on knowledge from previous BVSR trials. Campbell views all problem-solving efforts as blind trial and error in the sense that there wouldn't be a problem to solve if we had foresight of the possible solutions. It should be noted that blind variation does not imply random variation. In this theory, lack of foresight equates to blindness; blindness is the inability to purposefully and spontaneously generate the most useful variations.

> … in the general plan of blind-variation-selective-retention, it must be emphasised that insofar as thought achieves innovation, the internal emitting of thought trials one by one is blind, lacking prescience or foresight. The process *as a whole* of course provides "foresight" for the overt level of behaviour, once the process has blindly

> stumbled into a thought trial that "fits" the selection criterion, accompanied by the "something clicked", "Eureka"... that usually marks the successful termination of the process. (Campbell, 1960, p. 384)

Simonton (1999a) addresses four major objections that have been articulated about BSVR: sociocultural determinism, individual volition, human rationality and domain expertise.

The sociocultural argument suggests that creative contributions should not be attributable to the individual since they are the inevitable result of the zeitgeist. These creative-determinists point to multiple discoveries - where two or more people, working independently, develop the same contribution at the same time - as support for their argument. Simonton responds that a quantitative analysis of the occurrence of multiples, fits with what BVSR would predict and that the probability of any one person being involved in a multiple is a function of that person's productivity and the overall output of the field. The theory of evolution by natural selection itself was a multiple. Both Darwin and Wallace conceived the idea separately.

Individual volition notes that creators have goals, aspirations, and plans and that BVSR requires undirected variation. Simonton points out that the goal-directedness of creators is not incompatible with the BVSR theory. Even the greatest creative geniuses cannot will the next masterpiece or ground-breaking discovery into being. A look at the careers of virtually any creator will show failure frequently following on the heels of success. Simonton (1999b) has shown that creative failures are randomly dispersed with successes throughout a creator's career. A case in point: Darwin followed his theory of evolution through natural selection with his hypothesis of pangenesis. According to Yongsheng Liu, Darwin:

“suggested that all cells in an organism are capable of shedding minute particles he called gemmules, which are able to circulate throughout the body and finally congregate in the gonads. These particles are then transmitted to the next generation and are responsible for the transmission of characteristics from parent to offspring. If any cells of the parent undergo changes as a result of environmental change, they will consequently transmit modified gemmules to their offspring.” (Liu, 2008, p. 141)

Darwin’s pangenesis hypothesis was widely criticized and eventually replaced by Mendel's laws of genetic inheritance.

Some approaches to problem-solving are merely the application of logical, deliberate analysis using the most suitable heuristic. This human rationality view of creativity would appear to be completely incongruent with the BVSR theory of creativity. However, Simonton (1999a) argues that these approaches are still a form of BVSR. By progressing through problems from the simplest, for which one can retrieve an answer from memory, through more difficult problems that require the application of an algorithm, through to more difficult problems that require the use of heuristics, and finally to novel and complex problems where the number of potential solutions is very large, one is applying BVSR in a logical way. He notes that as problems become ever more unprecedented, the potential solution space and potential approaches to tackling the problem become so large that the choice of where to start becomes one of equal probabilities. “This status makes the probability of considering any one strategy highly contingent on the priming effects of random stimuli from the outside world. This process of priming problem-solving variations will be inherently blind” (p. 319).

Finally, the domain expertise argument suggests that once someone becomes sufficiently knowledgeable and practiced in a domain, they should be able to generate a series of successful creative ideas without the need for the trial and error suggested by BVSR. The essence of this argument is that if a champion chess player can consistently win games, a songwriter should be able to consistently write hits, a painter consistently paint masterpieces, a novelist consistently write best-sellers, and an inventor consistently invent successful products. Simonton (1999a) points out that there is no evidence that the ratio of hits to attempts increases with age, as would be expected if the domain expertise argument were true.

If the creative process depends on blind variation, then one prediction of this theory would be that the order and timing of creative successes during a person's career should be random. Huber (1998) found that for most inventors the timing of patents during their careers is random, fitting the Poisson distribution, thus lending some support to the BVSR theory. As Huber notes, "invention is a complex process subject to many variables. The Poisson parameter is just a handy summary surrogate for these many variables" (p. 239). Huber also points out that other forms of creativity may not follow the same pattern as invention and that "This randomness is also consistent with the abundant anecdotal reports of the difficulty of being creative on demand" (Huber, 1998, p. 239). Simonton (1999b), however, found a similar pattern in the publications of scientists. This randomness also seems consistent with the output of most musicians, many of whom will admit that they cannot predict which of their songs will become the most popular; and most marketing professionals will tell you that no one can predict what video will go viral on the internet.

2.1.3.6 Stage Theories

Poincare's essay on mathematical invention illustrates nicely what Wallas (1926) would later formalize as his stage theory:

It is certain the combinations which present themselves to the mind in a sort of sudden illumination, after an unconscious working somewhat prolonged, are generally useful and fertile combinations, which seem the result of a first impression… The conscious itself is narrowly limited, and as for the subliminal self we know not its limitations, and this is why we are not too reluctant in supposing that it has been able in a short time to make more different combinations than the whole life of a conscious being could encompass… Perhaps we ought to seek the explanation in that preliminary period of conscious work which always precedes all fruitful unconscious labour. Permit me a rough comparison. Figure the future elements of our combinations as something like the hooked atoms of Epicurus. During the complete repose of the mind, these atoms are motionless, they are, so to speak, hooked to the wall; so this complete rest may be indefinitely prolonged without the atoms meeting, and consequently without any combination between them.

On the other hand, during a period of apparent rest and unconscious work, certain of them are detached from the wall and put into motion… Then their mutual impacts may produce new combinations… the only combinations that have a chance of forming are those where at least one of the elements is one of those atoms freely chosen by our will. Now, it is evidently among these that is found what I called the good combination. Perhaps this is a way of lessening the paradoxical in the original hypothesis… It never happens that the unconscious work gives us the result of a somewhat long calculation *all made*, where we have only to apply fixed rules… Nothing of the sort, as observation proves. All one may hope from these inspirations, fruits of unconscious work, is a point of departure for such calculations.

As for the calculations themselves, they must be made in the second period of conscious work, that which follows the inspiration, that in which one verifies the results of this inspiration and deduces their consequences. (Poincaré, 1910, p. 330-334)

Between Bain – quoted in the previous section – and Poincaré, the labels for Wallas' stage theory seem to have been nicely laid out: *preparation* ("The mind being prepared beforehand" (Bain, 1868, p. 609)); *incubation* ("incubates in patient thought over the problem" (Bain, 1868, p.609)); *illumination* ("which present themselves to the mind in a sort of sudden illumination" (Poincaré, 1910, pp. 330); *verification* ("which one verifies" (Poincaré, 1910, pp. 334)). Stage theory is one of the earliest, most popular, and enduring creativity theories. Wallas articulated the theory in his classic work *The Art of Thought* in 1926. He based the theory on the accounts of highly creative individuals, including Poincaré and Hermann von Helmholtz (Wallas, 1926).

During the preparation stage the problem is defined, information gathered, acceptance criteria are set up for verification of possible solutions, and an attempt is made to consciously solve the problem by applying any means at one's disposal. Preparation involves the acquisition and application of relevant skills and knowledge. It is possible to find a solution to the problem during this stage, but if that doesn't occur, the process progresses to the incubation phase. During incubation, a break is taken from actively, consciously working on the problem. It occurs when conscious attention is directed elsewhere. Like the preparation stage, incubation can last from minutes to years, and when the right stimulus comes along, or the right association is made, the illumination stage is reached. This is the *ah-ha moment* when, in what appears to be a sudden flash of insight, an idea, a partial solution, or full solution, pops into conscious awareness. During the final stage of verification, the idea or solution is tested or applied and possibly refined (Carson, 2010; Kozbelt et al., 2010; Martindale, 1999; Plsek, 1997).

Most researchers now agree that, while the stage theory is useful, creativity is not a linear, step by step process (Kozbelt et al., 2010). Plsek (1997) points out that "while models are helpful in guiding our efforts, they are not to be used too rigidly" (para. 4). The stage theory makes more sense when viewed as a recursive model that may apply to parts of a problem, or the whole problem, such that one might be operating in various stages at the same time. Regardless of the criticism aimed at the stage theory, it is widely accepted by creativity researchers and highly creative individuals (Carson, 2010). It has also been modified and presented in many different variations (Plsek, 1997). Carson (2010) breaks the model into two different "pathways;" the spontaneous pathway, which includes incubation, and the deliberate pathway, which replaces incubation with problem-solving. Carson also breaks the preparation phase down into the steps: gather general knowledge and specific skills and problem finding for both pathways, with the additional step of immersion for the spontaneous pathway, and she breaks the verification stage into evaluation, elaboration and implementation for both pathways.

2.1.3.7 Creative Problem-Solving

The stages of incubation followed by illumination in Wallas' model, and many other stage models of creativity, suggest to many people that creativity is a mysterious process that cannot be controlled. Plesk (1997) points out how this is not necessarily the case: "Creative thinkers study and analyze, but they have trained their perception mechanisms to notice things that others miss. Creative thinkers verify and judge, but they expect surprises and avoid judging prematurely" (para. 7).

Creative Problem Solving (CPS) is a stage theory of a different sort. Most variations of Wallas' theory include incubation, or some variant of it, whereas the CPS model does not, making it more of a prescriptive, how-to model, versus Wallas' potentially predictive, model.

CPS consists of six steps arranged in three stages: *explore the challenge* consists of objective-finding, fact-finding, and problem-finding; *generate ideas* consists of idea finding, and *prepare for action* consists of solution-finding and acceptance-finding. Objective-finding is often based on a wish, a goal, or a dissatisfaction. Often, we may be given a vague, open-ended objective in a work situation. Fact-finding is the process of collecting all available, relevant information related to the situation and may go beyond facts to include feelings, hunches, gossip, and/or assumptions. Problem finding involves exploration of the facts, a search for opportunities, reframing issues, and changing perspectives until a clear definition of a problem is arrived at. Idea generation is about brainstorming to come up with as many possible solutions, or ways of addressing the problem, as possible. Solution finding includes strengthening and improving the best ideas, developing the evaluation criteria, and applying the evaluation criteria to select the most likely candidates. Finally, acceptance finding includes an analysis of what has to be done, by when, and by whom, in order to implement the solution ("Creative Problem Solving," 2016). The process involves a deliberate alternation between divergent thinking and convergent thinking.

Alex Osborn introduced Creative Problem Solving in his 1952 book *Wake up Your Mind*. Osborn (1953/1963) presented a revised and refined CPS model in his seminal book *Applied Imagination*. He later teamed up with Parnes to establish the Creative Education Foundation. Parnes continued to refine, teach and research CPS methods for many years ("Creative Problem Solving," 2016).

Parnes (1971) found, in a series of studies involving 350 students, that those who took the CPS course showed substantial gains in the number of ideas generated when compared to a control group. They also showed significantly superior quality on three tests of idea quality, greater improvement in quality in a fourth test – but not enough to be considered significant – and no superiority in a fifth measure. It was also observed that there was a persistence of these effects. Parnes' research showed that the CPS students demonstrated an increase in the measure of dominance in a personality test but did not show significant changes in measures of self-control or need-to-achieve, the dominance trait has been associated with creativity and includes characteristics such "as confidence, self-reliance, persuasiveness, initiative and leadership potential" (p. 273).

2.1.3.8 Componential Theories

2.1.3.8.1 Amabile's Componential Theory

Many theories of creativity propose that several components must converge for creativity to occur. These theories are often referred to as componential or confluence theories. Amabile's componential theory proposes that three components are necessary and sufficient for creative production: domain relevant skills, creativity relevant skills, and task motivation (Amabile, 1999; Weisberg, 2006).

The theory is typically illustrated as a Venn diagram – each component being represented by a circle – with the area where all three circles overlap representing the area where it is possible for creativity to occur. In Amabile's theory, domain-relevant skills include domain knowledge, any required technical skills, and innate talent in the domain. This includes perceptual ability, motor skills, formal and informal education, as well as innate cognitive abilities. Creativity-relevant skills, which were subsequently renamed creativity-relevant processes (Amabile & Pillemer, 2012), include a work style conducive to, and a cognitive style appropriate to, creative production, as well as implicit or explicit knowledge of heuristics for generating creative ideas. Creativity-relevant skills or processes are said to depend on training and experience in idea generation, as well as personality characteristics. The third component, task motivation, includes attitudes towards the task and perceptions of the individual's own motivation for undertaking the task. Task motivation depends on the initial level of intrinsic motivation, the presence or absence of influential extrinsic motivations, and the individual's ability to minimize extrinsic constraints (Conti, Coon, & Amabile, 1996).

A fourth component, the social environment, can influence each of the other components. In Amabile's own words: "Domain-relevant and creativity-relevant skills can be affected by training, modelling, and experience afforded by the social environment. However, the most immediate and prevalent influence of the environment is exerted on the motivational component, as evidenced by empirical research on the Intrinsic Motivation Principle of Creativity" (Amabile & Pillemer, 2012, p. 10).

These components may interact in several ways. For example, high levels of two components may have a multiplicative effect. There may be thresholds in components, below which creativity will not occur, regardless of the levels of the other components. It may also be possible for strength in one component to compensate for weakness in another (Sternberg & Lubart, 1999).

Amabile goes on to embed these components in a framework which includes a modification of Wallas' four-stage theory. Stage one is the problem or task presentation (later named problem or task identification) where, through external or internal stimulus, the person becomes aware of a need or opportunity to solve a problem or address a need. Task motivation plays a significant role here, determining whether and how the person will engage with the task. Second is the preparation stage, where domain-relevant skills come into play as the person gathers information and possibly learns new skills. In the third stage, response generation, creativity-relevant skills and task motivation play a role as memory and the immediate environment are searched to generate response possibilities or solutions. In the response validation stage, domain-relevant skills are applied to evaluate the usefulness and originality of the possible solutions generated. In the fifth and final stage of Amabile's theory, outcome, the outcome of the process is evaluated. If there is complete success, the process ends. If there is progress, the person will likely return to stage one and iterate through the stages again (Amabile, 1996; Amabile & Pillemer, 2012; Lubart, 2001).

2.1.3.8.2 Investment Theory

The investment theory is, essentially, a componential (or confluence) theory with a buy-low, *sell-high* theory tacked on. That is, the theory hypothesizes that creative people are those who will pursue ideas that are of unknown value, or are out of favour, but have growth potential. When first presented to others, these ideas, and their creative champion, often encounter resistance. The creative individual perseveres, despite the resistance, and eventually 'sells high' moving on to the next new idea (Sternberg & Lubart, 1991). Sternberg (2012) suggests that those who are able to accomplish this have acquired a creativity habit. He goes on to explain that, according to the investment theory, creativity requires a confluence of knowledge, intellectual abilities, thinking styles, personality, motivation and environment.

Knowledge about a field is seen as necessary, but not sufficient, to produce the creative ideas needed to move a field forward. However, Sternberg and Lubart (1995) see knowledge as a double-edged sword. Knowledge about a field can result in an inability to see beyond the learned perspective.

Intellectual abilities are seen as being made up of three elements: synthetic, analytic and practical intelligence. Synthetic intelligence is the ability to see things in new ways, while analytic intelligence is the ability to recognize and define problems and to determine which of many proposed solutions is the most promising. Finally, practical intelligence includes the ability to convince others that a creative idea has value.

Thinking style is the way a person chooses to think, with a creative person choosing to think in novel ways. However, even if one has the knowledge, intellect, and thinking style, needed to be creative, in order to actually produce creative work, the individual needs to possess the personality characteristics that will make it more likely that s/he will make use of her creative potential. These include, according to investment theory, a willingness to persevere in the face of obstacles, a willingness to take risks, a tolerance for ambiguity, and openness to experience. Like Amabile (Amabile, 1996), Sternberg and Lubart view intrinsic motivation as an important factor in the realization of creative potential and they conclude that extrinsic motivation can play a positive or negative role in creativity.

Finally, the environment can support and encourage creative thinking, increasing the likelihood that people will live up to their creative potential, or it can be a source of obstacles that will prevent many individuals from expressing their creativity (Weisberg, 2006).

Sternberg (2012) notes that creativity is hypothesized to be more complex than just a simple summation of a person's level of each component. It is expected that there may be partial compensation, in which a strength in one area may compensate for a weakness in another; multiplicative effects, where high levels in two areas may have a multiplying effect, rather than simply a summative effect; and there may be thresholds for some components, below which no creativity is possible, regardless of the levels of the other components. For example, knowledge (Sternberg, 2012) and intelligence (Plucker & Renzulli, 1999) have both been proposed as having a threshold level.

2.1.3.9 Systems Approach

Hennessey and Amabile (2010) argue that a deeper understanding of creativity requires a systems view of creativity that recognizes interrelated forces operating at many levels, and that interdisciplinary research is required. Their review of the field of creativity for the Annual Review of Psychology uncovered an interesting fact. Hennessey and Amabile asked 26 creativity researchers, who they felt had made the most significant contributions to the creativity literature, to nominate up to 10 papers, published since 2000, that they considered 'must have' references. Of the 110 papers suggested, only 7 were suggested by 2 colleagues, and only 1 was suggested by 3. This, as they note, indicates a great deal of fragmentation in the field. They went on to say:

> We believe that more progress will be made when more researchers recognize that creativity arises through a system of interrelated forces operating at multiple levels, often requiring interdisciplinary investigation. Figure 1 presents a simplified schematic of the major levels at which these forces operate. The theory is simplified because, as noted, existing research does cross levels. And, in fact, the "whole" of the creative process must be viewed as much more than a simple sum of its parts. Individuals are much more than their affect, cognition, or training. And social environments or groups may be embedded within particular cultures or societies, but they also crosscut them, as when multiple cultural or religious groups live together within a society. (p. 571)

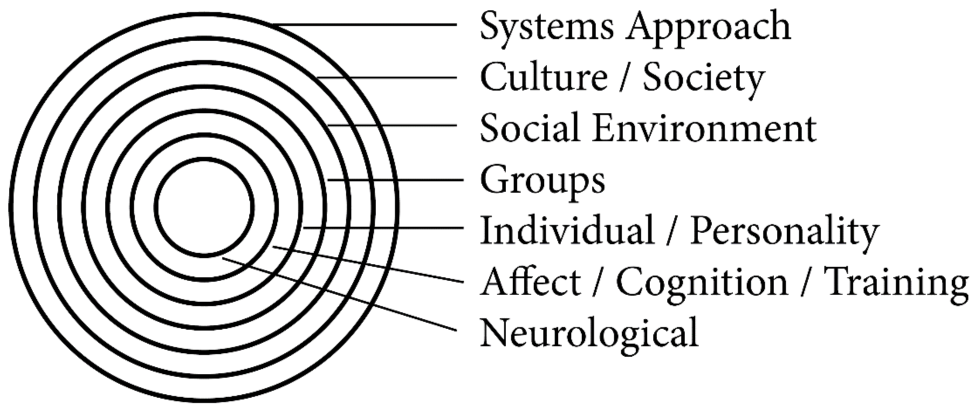


Figure 1: Systems Approach (Adapted from, Hennessey & Amabile, 2010)

Csikszentmihalyi claims that rather than try to find the answer to *what* creativity is, we should be asking *where* creativity is. He asserts that this question should precede any attempts to define, measure, or enhance creativity (Csikszentmihalyi, 1988).

Is creativity located in the creative person's head? In the thought or action of the creative person? Or perhaps it resides in the creative works of the person? Csikszentmihalyi concludes that creativity cannot be isolated in individuals or their works; that it cannot be separated from "the social and historical milieu in which their actions are carried out" (Csikszentmihalyi, 1988, p. 325). Csikszentmihalyi (1990) proposes a systems view of creativity which is based on the interaction of a person with a domain and a field. Put succinctly, "the domain transmits information to the person, the person produces a variation, which may or may not be selected by the field, and the field will, in turn, pass the selected variation to the domain" (p. 200).

In the system, as Csikszentmihalyi sees it, the domain is the body of knowledge, set of rules, culture, and symbol system that exists about a particular discipline at a particular time. The person, in this tripartite system, is an individual who has assimilated the knowledge and rules of the domain well enough to use the established culture and symbol system of the domain to go beyond any previous performances, while not going so far as to be ignored or censored by the field. The field consists of other individuals who know the domain's rules and vocabulary, and act as gatekeepers, deciding which individual efforts meet the criteria of the domain, which depart from the accepted domain rules in a manner deemed to be creative, and which deviate from the rules in a manner deemed deviant. Those ideas or performances determined to be creative by the gatekeepers become part of the domain's cultural milieu for future efforts and future generations (Csikszentmihalyi, 1988, 1990; Kozbelt et al., 2010).

In the systems view of creativity, the question of where creativity resides cannot be answered by referencing the creative person, or the individual's creative product. Creativity results from interaction among the three subsystems - the individual, the field, and the domain. Thus, the answer to Where is creativity? is that it resides within and throughout the system.

It should also be noted that the system is dynamic; the concept of what is creative can be expected to change over time, from place to place, and from one domain to another. "Creativity exists only in specific social and historical contexts" (Csikszentmihalyi, 1988, p. 326). Therefore, we cannot determine if something is creative merely by looking at it; it may be a copy of something produced many times before. One needs the historical and social context to determine if something is truly novel and of value, so it is typical that we need experts to tell us what is creative (Csikszentmihalyi, 1988). For example, what if we were told, by expert forensic art historians, that the Mona Lisa was, in fact, not painted by da Vinci; that it was painted by an unknown artist who copied the lost work of another famous artist while applying da Vinci's style and forging his signature? By many definitions of creativity, such a revelation would cause the painting to go from being considered creative to being considered not creative (although it could be argued that applying da Vinci's style while copying the work of another artist is in itself creative). It may still be considered technically good and aesthetically pleasing, but not creative. So, did creativity reside in the painting, and suddenly vanish? Did it live in the artist, resulting in the painting being considered creative when it was connected to da Vinci, but losing this designation when it was later determined to be painted by a less creative individual? Or did it/does it reside, as Csikszentmihalyi seems to suggest, in the person-domain-field triumvirate, even as the three may change over time. Looked at in this way, the product perspective is noticeably absent from Csikszentmihalyi's systems view.

In Csikszentmihalyi's "theory the creative process takes place outside the person, in the *interaction* between the three subsystems. In such a scheme, the individual does not have a privileged epistemological position" (Csikszentmihalyi, 1990, p203). To illustrate his point, he argues that the sudden flourishing of creativity in the early part of fifteenth-century Florence cannot be understood by looking at and trying to understand individuals, but that it can be understood by looking at the interaction of domains, fields, and individuals. That is, it required supportive social and cultural conditions, combined with individual creative potentials, to result in the sudden flourishing of creativity we refer to as the renaissance (Csikszentmihalyi, 1990). He also relates the interaction of the three elements to Campbell's (Campbell, 1960) blind variation and selection retention theory: "The specific functions of the three elements in the creative process are analogous to the three aspects of all evolutionary processes: variation, selection, and retention" (Csikszentmihalyi, 1990, p. 204). The analogy being that individuals produce variations in a domain, the field selects, and the domain retains the selected variation by transmitting it to the next generation of individuals.

While Csikszentmihalyi's system's theory focused on academic researchers, similar views have been expressed about visual art. Newton and Donkin (2011), for example, argue that creativity is not confined to the artist, but extends to the viewer who must interpret and make sense of what they are viewing.

Gangadharbatla (2010) argues that, since the original systems approach was proposed, technology has become a dominant force, influencing the individual, society, and most domains, and, therefore, the theory should be revised to include a new "technology component." However, one would think that technology is just another environmental factor; one that may deserve special mention, but an environmental factor none the less.

2.1.3.10 Summary

There are no all-encompassing theories of creativity. That is, none address levels from neurons to societies, and everything in between, while offering an explanation of the variations in creative abilities and creative outputs at each level. This is a challenging task, but a framework for such an all-encompassing theory would be a good start.

In a review of creativity theories, Kozbelt, Beghetto and Runco (2010) sorted what they referred to as the "major contemporary theories of creativity" (p. 20) into ten major categories. The "multitude of theoretical perspectives" led to several theories being referenced in each of the ten categories. As noted above, Hennessey and Amabile (2010) referred to this as fragmentation in the field and noted the need for researchers to "recognize that creativity arises through a system of interrelated forces operating at multiple levels" (p. 571). However, this seems to be happening. It can be seen in the progression to more and more complicated models. For example, Amabile's (1977) componential model evolved to include the possibility of multiplicative effects (Amabile, 1996) and eventually became the dynamic componential model (Amabile & Pratt, 2016).

In parallel with the progression of Amabile's model, the investment theory (Sternberg & Lubart, 1991) added more components and proposed more interactions, and systems theories add levels, with interactions between the levels. Meanwhile, as creativity theories are becoming more complicated, the word *complex* seems to be used more often to describe the topic (see, for example, Hennessey & Amabile, 2010; Kozbelt et al., 2010).

Systems, *interrelated*, *complex*, and *interactions* are all words that seem to be increasingly used in connection with creativity theories. It is surprising that no one has seen the connection to complex adaptive systems theory and developed a complex adaptive systems theory of creativity. As will be seen in the rest of this dissertation, developing such a theory is a large undertaking – one that will begin within this document.

The articles presented in this dissertation begin the work of developing a comprehensive, complexity theory of creativity that will address the shortcomings of existing theories.

2.1.4 Assessing Creativity

The creativity research – that is, the attempt to better understand all facets of creativity – is one of the major reasons to assess creativity. Others include formative evaluation, mastery assessment – to help guide a student in improving and reaching their goals, or for the professional development of someone working, or hoping to work, in a creative role – and identifying gifted students for guidance and admission to programs.

Beghetto (2005) in *Does Assessment Kill Student Creativity?* concludes that, done correctly, assessment can support creativity. Kaufman, Plucker and Baer (2008) state that:

> creativity is a natural candidate to supplement traditional measures of ability and achievement. A growing trend among admission committees and educators is a focus on non-cognitive constructs, such as emotional intelligence, motivation, and creativity, to supplement current measures. Creativity is a prime candidate to be such a supplement. One reason is that creativity is related to intelligence and academic ability, yet not so closely related as to not account for additional variance. Another promising reason is the reduction in gender and ethnicity differences. (p. 10)

This section will explore some of the many ways researchers have attempted to assess creativity and creative potential.

2.1.4.1 Psychometric Assessment

As will be discussed in a subsequent section on the enhancement of creativity, most literature reviews conclude that creativity training works. These conclusions, however, are problematic. Most of the studies relied on the Torrance Tests of Creative Thinking (TTCT), or similar divergent thinking tests. Yet divergent thinking is only one aspect of creativity. An important one, to be sure: "there is a legitimate case to be made that divergent thinking is a key component of creativity and, more specifically, creative problem solving" (Kaufman et al., 2008, p. 16). However, divergent thinking is certainly not the only component of creativity.

Divergent thinking tests have come to dominate psychometric approaches to creativity assessment for two reasons: 1) divergent thinking is the only cognitive aspect of creativity that is reasonably well defined and 2) assessing divergent thinking ability is a relatively straightforward and easy task.

Torrance, Ball and Safter (2008) provide the following definitions related to the scoring of Torrance Tests of Creative Thinking:

- Verbal; the verbal TTCT is composed of written responses to questions posed about an illustrated scene,
- Figural: the figural TTCT consists of constructing pictures based on partially completed pictures, lines, or shapes, and giving the completed picture a title,
- Fluency: the number of ideas a person expresses through interpretable responses that suit the stimulus in a meaningful manner,
- Flexibility: a measure of the subject's tendency to 'break-set' or resist inertia in thinking; scored based on the number of categories used in responses,
- Originality: a measure of the statistical infrequency and unusualness of responses,
- Elaboration: a measure of the tendency to go beyond the minimum required.

In addition to the fact that divergent thinking is not the sole aspect of creativity, there are several other problems associated with using these tests to assess creativity.

1. They are generally time-constrained; both from the time given to complete each section, and the time of day – and day of the week – that the test is completed. This is one aspect of this approach to assessing creativity that removes choice, and choice has been shown to be a factor in increasing the likelihood of creativity (Amabile, 1996; Sawyer, 2012).

2. The tests are either linguistic-based or visually-oriented. This removes another choice from the participant – that of the domain. Many people are more capable of expressing their creativity in a specific domain, particularly when they are in the early stages of their creative development.

3. They typically take place in classroom or laboratory-like test conditions. These conditions are seldom, if ever, designed and arranged with fostering creativity in mind (Seelig, 2012).

4. A participant's score can be increased substantially just by getting a brief overview of how they are scored, that is, fluency, flexibility, originality, and elaboration; as defined above. This may be one reason for generally poor and wide-ranging test–retest reliability coefficients of 0.50 to 0.93 (K. H. Kim, 2006).

5. While the TTCT claims high inter-rater reliability, Grohman, Wodniecka, and Klusak, (2006) found that people with high divergent thinking skills tend to underestimate the uniqueness of others. It has also been noted by Runco and Chand (1994) that people are less able to evaluate highly original ideas than less original ideas. Blair and Mumford (2007) concluded that "people have a marked disdain for original and risky ideas" (p. 216). These findings lead to skepticism regarding the value of the TTCT as a norm-referenced test.

6. The TTCT, and similar tests, only measure divergent thinking and remote association ability (which is just another way of looking at divergent thinking). While a high level of these skills increases the chances that a person will be creative (Cramond, 1994), there are many other factors that may help or hinder a person being creative. For instance: skill at evaluating ideas, persistence, persuasiveness, motivation, opportunity, and many environmental, social and cultural factors.

In short, a high level of divergent thinking ability is not sufficient for creativity, and it may not even be necessary.

To its credit, the Torrance test has been shown to be a better predictor of creative achievement than other measures of creativity or divergent thinking (K. H. Kim, 2011) and better than IQ tests (K. H. Kim, 2006). On the other hand, correlations of 0.39 to 0.48

should not be considered significant enough to consider using such tests to make predictions – or decisions. On balance, the literature suggests that divergent thinking tests may be useful alongside other evaluation methods, but they should not be relied upon on their own, and they should be interpreted with caution.

2.1.4.2 Assessment by Others

Assessing the creativity of others may be done by a teacher, peer, or parent assessing the "personality traits, creativity-relevant abilities, motivation, intelligence, thinking styles, emotional intelligence, or knowledge" (Kaufman et al., 2008, p. 84) of another person. This is most commonly done by a teacher rank-ordering their students based on their knowledge of the students and their work, along with the teachers' conceptions of creativity.

As one would expect, this approach has problems with validity (J. C. Kaufman et al., 2008), and does not allow for comparisons across groups. In an attempt to overcome some of the shortcomings of this approach to assessment, several different checklists of creativity have been developed such as: *The Scales for Rating the Behavioural Characteristics of Superior Students*, which includes creativity as one of its 14 scales; the *Williams Scale Creativity Assessment Pack*; the *Ideal Child Checklist*; and the *Gifted Evaluation Scale*. Each has received mixed reviews for validity and usefulness (J. C. Kaufman et al., 2008).

Kaufman, Plucker and Baer concluded their assessment of assessment by others with the following thoughts:

> As Torrance (2000) advised, in discussing checklists and rating scales as instruments for assessing the creativity of young children:

> "These instruments often have strong intuitive appeal but frequently lack the appropriate psychometric properties of validity and reliability… [T]hey cannot be used as exclusive means of identification."
>
> They can, however, serve as one small piece of an assessment program that when combined with other measures like divergent thinking tests, self-assessment checklists, and ratings of the creativity artifacts (judged using the Consensual Assessment Technique) can help paint a richer picture of a student's creative abilities. (p. 99)

Considering the time and effort involved to achieve Kaufman, Plucker and Baer's 'richer picture', and the questionable validity and reliability of the resultant picture, a more appropriate approach – for instances where assessment by others may be of some use – might be to educate teachers on creativity and creative children.

2.1.4.3 Assessment of Self

The simplest means of using self-assessment as a method to assess individual creativity is to ask people to rate their creativity on a scale of 1-10 or to estimate where they would land on a normal distribution curve of creativity. Research has also been performed asking individuals to rate their creativity in a number of domains. Any study using these techniques should be viewed in light of increasing evidence of our limited ability to assess our own abilities and performance with any degree of accuracy (Dunning, 2005):

> The Greek philosopher Thales… lamented that "knowing thyself" was one of the most difficult tasks people face—certainly more arduous than the easiest task he could think of, which was, of course, giving advice to others. Recent evidence of

> psychological research gives credence to Thales's lament about the human inability to achieve accurate self-impressions. If one scavenges through the literature, one finds ample evidence that the impressions people have of themselves seem to be detoured away from realistic self-views (p. 3).

While self-efficacy is an important quality when it comes to creativity, it seems to be far from a sufficient quality to ensure creativity.

Another approach to self-assessment of creativity, perhaps the most common, is the personality inventory. One factor – openness to experience – stands out in its relation to a variety of creativity measures. The relationship was also found to hold up in an extensive 2003 longitudinal study by Feist and Barron (J. C. Kaufman et al., 2008).

2.1.4.4 Consensual Assessment Technique

In the late 1970s, Teresa Amabile was doing her doctoral research in creativity at Stanford. During her work, she developed the Consensual Assessment Technique (CAT) to get around the criterion problem. The criterion problem of what criteria creativity should be assessed against. This, of course, depends on the definition of creativity used. In discussing various definitions of creativity and the criterion problem, Amabile arrived at a very specific definition of creativity, which also led to the CAT:

> First, of course, they [definitions of creativity] all involve the criterion of novelty; something new must result, something unconventional or surprising. Second, limits are placed on the novelty of the product. It cannot be merely uncommon, or bizarre, but it must also be appropriate, in some way a fitting solution, response, or expression. This, then, is the definition of creativity which will be adopted here, in the spirit of both heeding intuition and utilizing the foundation that has been

> established by previous theorists: A person is creative to the extent that he or she produces a novel response or expression, provided that the response is, in the assessment of relevant judges, not only novel but also appropriate. Likewise, a product is creative if, in the assessment of relevant judges, it is both novel and appropriate. (Amabile, 1977, p. 43)

Using this approach, Amabile had a small panel of independent judges assess works for creativity. Judges were:

- expected to be familiar with the domain
- not given any definition of creativity
- to judge independently
- asked to evaluate products relative to each other based on creativity and other dimensions such as technical aspects and aesthetic appeal (Amabile, 1977).

The combined results of the judge's independent assessments were then taken as the final word on what was creative and what was not. Without a definition of creativity, they were expected to use an 'I'll know it when I see it' approach. In many respects, this is a reasonable, workable definition, although it is one that is challenging to operationalize. On the other hand, the way CAT has been applied limits the usefulness of the research done to-date.

1. It has been applied in classroom or laboratory settings, which are often not conducive to creativity.

2. It has been applied using a typical scientific experiment approach. That is, the location, time, duration, and task are all predetermined by the researcher, leaving the participants few choices. Creativity researchers, including Amabile, have concluded that

choice is an important factor in allowing creativity to flourish (e.g. Amabile, 1996, p. 169 and 249).

3. The tasks used are more 'real world' than most divergent thinking tests of creativity (although not all; Torrance's improvements for a toy elephant exercise, for example, could be considered more real-world than most exercises used with a CAT), but they are still highly constrained and restrictive. Any real measure of creativity must be closer to boundless in its constraints, removing as many restrictions as possible.

4. Amabile argues that the assessments must be done by domain experts. The argument is sound for any fields where there are gatekeepers (music producers, book publishers, movie producers, art gallery managers, journal review committees, etc.), but the internet has the potential to create democratization of content, doing away with, or working around, gatekeepers. Crowds – consisting of novices and geniuses alike – are inheriting the power to decide what is creative.

2.1.4.5 Summary of Assessment

In a review of measures of creativity, Hocevar and Bachelor (1989) expressed concern with reliability, discriminate validity and nomological validity throughout the literature. However, they were particularly concerned with discriminant validity, noting that judges generally were unable to discriminate between creativity and other constructs such as intelligence, achievement, competence, technical skill, and aesthetic value. The third article in this dissertation proposes a definition and a way of understanding creativity that should help avoid this discrimination problem.

2.1.5 Enhancing Creativity

Is creativity a genetic gift bestowed upon some fortunate souls while others are left wanting, or is it something that can be nurtured in all of us? Can creativity be taught? Can it become, for each of us, an endlessly renewable resource that can be tapped into at any time? With a broad range of creativity enhancement techniques applied liberally for at least 50 years, one might think a clear answer to these questions would be relatively easy to find. Unfortunately, that is not the case.

The perceived need for creativity has led to a proliferation of creativity enhancement programs, yet the research has not kept pace, leading to the potential for creativity 'snake oil salesmen' and wasted time and resources (Puccio, Firestien, Coyle, & Masucci, 2006). Yet, with or without the backing of sound research, these programs abound. Solomon (1990) found, through the use of a survey, that 25% of organizations with 100 or more employees offer creativity training of some sort.

The following is a brief overview of the many different approaches to enhancing creativity.

2.1.5.1 Cognitive Approaches

Given the wide range of factors that have been shown, or theorized, to have an effect on creativity, it is not surprising that a multitude of programs has been developed to enhance creativity; however, the vast majority of these have been cognitive programs related to the creative process. Some of the more popular of these are reviewed here, while less common cognitive approaches, and those lacking in research studies, are briefly discussed at the end of this section.

2.1.5.1.1 Brainstorming

In the 1930s Alex Osborn began developing techniques to enhance idea generation at his advertising firm. He had found that, on their own, individuals were not coming up with the quantity, or quality, of ideas he felt they were capable of, and that conventional meetings seemed to be hampering idea generation (Amabile, 1996). Osborn formalized his observations as a set of rules for an idea generation technique and coined the term brainstorming. Osborn published his set of rules for the now-famous technique in his seminal work *Applied Imagination* (1963)[9]:

> (1) Criticism is ruled out. The adverse judgment of ideas must be withheld until later.
>
> (2) 'Free-wheeling' is welcomed. The wilder the idea, the better; it is easier to tame down than to think up.
>
> (3) Quantity is wanted. The greater the number of ideas, the more the likelihood of useful ideas.
>
> (4) Combination and improvement are sought. In addition to contributing ideas of their own, participants should suggest how ideas of others can be turned into better ideas; or how two or more ideas can be joined into still another idea. (p. 156)

In 1954 Osborn founded the Creative Education Foundation and in 1955 he began a collaboration with Dr Sidney J. Parnes, which led to the Osborn-Parnes Creative Problem Solving Process (see next section). Osborn (1963) cites many examples of success with

---

[9] *Applied Imagination* was originally published in 1953; however, Osborn outlined the elements of brainstorming in the 1948 publication, *Your Creative Power*.

brainstorming, but he does not cite any scientific studies that specifically focused on brainstorming, largely because he viewed brainstorming as just one step in a larger process:

> In summary, let's put group brainstorming in its place. For one thing, it is only one of the phases of idea-finding which, in turn, is only one of the phases of the creative problem-solving process. And let's bear in mind that group brainstorming is meant to be used—not as a substitute—but as a supplement. (p.191)

On the other hand, Stein (1974) notes that "Brainstorming is the most researched of all the procedures for creative problem solving" (p. 37, vol. 2). The research clearly supports the notion that brainstorming results in more ideas than techniques that allow or encourage judgment or evaluation during idea generation. However, in terms of the quality of ideas resulting from brainstorming, the results are less conclusive, with some research supporting brainstorming, while other research shows no improvement when applying the technique. Research has also shown that group brainstorming holds no advantage over individual brainstorming (Stein, 1974; Scott et al., 2004), a fact which Osborn (Osborn, 1963) seemed to be well aware of:

> "Despite the many virtues of group brainstorming, individual ideation is usually more usable and can be just as productive. In fact, the ideal methodology for idea-finding is a triple attack: (1) Individual ideation. (2) Group brainstorming. (3) Individual ideation. And, of course, each of these procedures can be far more productive if the deferment-of-judgment principle is consistently followed." (p. 191)

Scott, Leritz, & Mumford (2004), in their meta-analysis of 70 studies on the effectiveness of creativity training, found that brainstorming training had a strong positive correlation with attitude and behaviour of subjects with respect to creativity (correlation coefficient: r = 0.35), a marginal correlation with problem-solving (r = 0.19), and virtually no correlation with performance (r = 0.08). They also found surprisingly little correlation between brainstorming training and divergent thinking (p. 377).

There are many challenges to effectively researching the premises of brainstorming. While accounting for quantity is a relatively straightforward task, determination of the quality of ideas presents challenges, such as, what is the definition of quality, and who is the arbiter of quality. The choice of a facilitator can have a large impact on the results obtained from a brainstorming session, as can the degree of training and the instruction provided. As noted by Stein (1974) in an introduction to his extensive review of the research regarding brainstorming[10]:

> It should therefore not be surprising to the reader that studies by adherents of brainstorming support brainstorming while some other publications support it less strongly or not at all… It is insufficient to believe that the instructions as transmitted are adequate. It is important to know that the instructions have 'taken' and whether they have or not should be determined in some way other than with the same test that is used to determine the number and quality of ideas produced… It may still be that subjects who defer judgment produce more and better ideas than individuals who do not defer judgment. All that can be said is that in the studies previously mentioned and in those which shall be presented one cannot be certain that researchers were actually studying individuals who deferred judgment. And, if

[10] In excess of 120 pages in his two-volume examination of stimulating creativity.

subjects were not deferring judgment then the researchers were not conducting a good test of brainstorming's hypotheses. (p. 38-39 vol. 2)

While Stein may sound like an 'adherent of brainstorming', he goes on to produce a very extensive and balanced view of the research published prior to 1975. Although it seems that virtually every facet of brainstorming has been studied "It has been scrutinized from practically every angle and in terms of almost every variable" (p. 37), Osborn's (1963) recommended 'individual-group-individual' technique has been neglected. "This tripartite sequence has not been studied. Research has concerned itself with the effects of two sequences— individual followed by group and group followed by individual" (Stein, 1974, p. 98). Perhaps equally surprising is Stein's comment that "Actually, little if any effort has been expended in the study and evaluation of training in brainstorming alone. Such work has usually occurred when brainstorming has been included in another procedure that has included other techniques to stimulate creativity as in creative problem-solving," the subject of the next section of this dissertation. A search of the literature did not reveal any change since Stein's findings in 1974. That is, no studies of the effect of brainstorming training, independent of other techniques, while applying the individual-group-individual technique, were found.

2.1.5.1.2 Creative Problem-Solving

Alex Osborn introduced Creative Problem Solving (CPS) in his 1952 book *Wake up Your Mind* (Osborn, 1963). He revised and refined the CPS model, reintroducing it in his book *Applied Imagination* in 1953. As discussed in the previous section, Alex Osborn later teamed up with Sidney Parnes at the Creative Education Foundation. Parnes continued to refine, teach and research CPS methods for many years ("A Little History," 2013). CPS consists of six steps arranged in three stages: *explore the challenge* consists of objective finding, fact-finding, and problem finding; *generate ideas* consists of idea finding, and *prepare for action* consists of solution-finding and acceptance-finding.

Objective-finding is often based on a wish, a goal, or a dissatisfaction. Often, we may be given a vague, open-ended objective in a work situation. Fact-finding is the process of collecting all available, relevant information related to the situation and may go beyond facts to include feelings, hunches, gossip, and/or assumptions. Problem finding involves exploration of the facts, a search for opportunities, reframing issues, and changing perspectives until a clear definition of a problem is arrived at. Idea generation is about brainstorming (see the previous section). Solution finding includes strengthening and improving the best ideas, developing the evaluation criteria, and applying the evaluation criteria to select the most likely candidates. Finally, acceptance finding includes an analysis of what has to be done, by when, and by whom, in order to implement the solution ("The CPS Process," 2013). The process involves a deliberate alternation between divergent thinking and convergent thinking.

As noted in the section on creativity theories, Parnes (1971) found that those who took s CPS course demonstrated an increase in the number of ideas generated, compared to a control group. Their ideas also showed higher quality. The effects were also shown to be persistent. Parnes' work also revealed that students who took a CPS course had an increase in *dominance* in a personality test, but without a corresponding increase in measures *of self-control* or *need-to-achieve*.

In Torrance's (1972a) survey of 142 studies, he found that CPS, and variations of the model, were the most common methods used in studies to teach children to think creatively. The studies also revealed that the CPS had the highest success rate, with 20 out of 22 studies reporting successful outcomes. In most studies the outcomes were determined based on the Torrance Test of Creative Thinking; however, several of them also focused on Guilford's alternative uses test.

Rose and Lin (1984) completed a meta-analysis of 46 studies, eight of which were based on CPS and its modifications. In their analysis, CPS showed the greatest effect size (ES = 0.63) with training explaining over 40% of the variance in scores.

2.1.5.1.3 Synectics

Synectics is a creativity-enhancing program developed by George Prince and William Gordon (Gordon, 1961), beginning in 1944. Prince and Gordon observed an individual as he talked his way through an invention process. They went on to compare their results to other individuals, then they began recording group sessions. "The Greek word Synectics means the joining together of different and apparently irrelevant elements" (p.3).

Synectics research is based on the assumption that the creative process can be described, that such a description could be used to enhance the creative output of individuals or groups, that creative processes in arts and science are essentially the same, and the creative process employed by individuals is analogous to that employed by groups. Synectics theory is based on the hypotheses that creativity can be enhanced if people: "understand the psychological process by which they operate" (p. 6), the emotional component of creativity is more important than the intellectual, and that it is the emotional and irrational elements that have the greatest impact on the chances of problem-solving success. Synectics seeks to make the strange familiar and the familiar strange by using metaphors and analogies. Use of emotion is emphasized, for example, how it feels to be a spring (personal analogy), and judgement is deferred during idea generation. Other forms of analogy applied in Synectics include:

- direct analogy, where the characteristics of one object or process are superimposed onto another to arrive at a new or enhanced product or process,
- symbolic analogy uses images to describe the problem, or its potential solution, often in a poetic way,
- fantasy analogy "accepts Freud's wish-fulfilment theory of art, but turns it onto technical invention as well and uses it operationally" (p. 48). That is, wishes for the ideal product are expressed as fantastical ideas, without regard for any sorts of limitation – laws of physics can be ignored and magic is entertained as possible (Gordon, 1961).

There is relatively little research published on the efficacy of Synectics training; however, Gordon (1961) did state:

> To date Synectics research has shown that it is possible to teach at least certain people to adopt certain thinking habits which will increase the probability of success in problem-stating, problem-solving situations. Also it appears reasonable to expect that people with 'Synectics potential' can be identified. Further, it seems that once these thinking habits are learned they are never totally forgotten. These habits may grow hazy in the course of automatic, as opposed to conscious, employment, but they can be brought back clearly and distinctly through the formal use of the operational mechanisms at a conscious level. (p.154)

2.1.5.1.4 Purdue Creative Thinking Program

The Purdue Creativity Program, PCP (later renamed the Purdue Creative Thinking Program (PCTP) was developed in 1965 by John F. Feldhusen to increase the creative potential of children in grades three to eight. The program was designed to foster verbal and visual divergent thinking skills, increasing fluency, flexibility, originality and elaboration (all measures of the Torrance Test of Creative Thinking (TTCT), or the Minnesota Tests of Creative Thinking (MTCT), as the test was named at the time). It consists of 28 lessons, with each lesson consisting of a three to four-minute presentation about a creativity principle or idea for improving creativity, followed by a an eight to ten-minute story about an American pioneer, followed by three or four exercises, linked in some way to the story, and designed to provide practice in the divergent thinking skills mentioned above. The lessons were originally broadcast over WBAA radio station, but after the initial study, they were recorded and delivered by audiotape (Amabile, 1996; Feldhusen & Clinkenbeard, 1986; Feldhusen, Treffinger, & Bahlke, 1970; Feldhusen, Speedie, & Treffinger, 1971).

Feldhusen, Speedie and Treffinger (1971) reported that the initial research conducted using the program involved two classes each from grades three, four and five, with six comparable classes used as a control group. After the program, students in the experimental group were found to be superior to the control group on "verbal and non-verbal originality and language achievement" (p. 87). Further research included 48 classes of fourth, fifth and sixth grades. The classes were selected randomly from a population of about 100. Two classes at each grade level were randomly assigned to one of eight groups. Seven of the groups received a component, or a combination of components, of the three-component Purdue Creativity Program, and one group was the control group, as such they were given pre and post-tests only. They found support for the material, with the printed exercises being particularly effective.

Feldhusen, Treffinger and Bahlke (1970) also discussed another study of the program, completed by Robinson, involving 66 students with 33 students serving as a control group. The result was that the experimental group "made highly significant gains on all creativity scores derived from the MTCT" (p. 90).

Torrance's (Torrance, 1972b) meta-analysis of 142 studies aggregates the Purdue Creativity Program with the Productive Thinking Program, the Myers and Torrance Ideabooks, and a number of other programs, under the heading of complex programs involving packages of materials. Out of 25 studies, he rates 18 as being successful. Closer examination reveals that five of the studies employed the Purdue Creativity Program and all showed at least some degree of success. However, it's interesting to note that Torrance states that without the involvement of the class and the teacher in the use of the programs, the success rate is low. Yet most of the studies conducted using the Purdue Creativity Program did not include teacher involvement. Feldhusen, Treffinger, and Bahlke (1970) even note, after reporting on three studies, that "New research is being conducted at Purdue to investigate other factors which may influence the effectiveness… including teacher involvement…" (p. 89).

Feldhusen, Speedie, & Treffinger (1971) noted that in the exercises the need for divergent thinking – many possible answers rather than one correct answer – was stressed. They go on to give an example of one of the exercises: "Suppose that Henry Ford had not invented the automobile, and…" Hopefully, their intention is not to take creativity so far that rewriting history is considered a good thing (while Henry Ford may have been responsible for designing the Model A and Model T – and some might consider him the inventor of the assembly line – he certainly did *not* invent the automobile).

While Scott, Leritz, and Mumford (2004) do not present their meta-analysis of 70 research publications in a way that allows studies involving the Purdue Creativity Program to be separated out, it is clear that they aggregated them into their divergent thinking grouping, noting that it is one of the best-known programs aimed at increasing divergent thinking. They stated that "Given the focus of creativity training on the development of creative thinking skills, it was not surprising that the largest effect sizes were obtained in studies employing divergent thinking (delta = 0.75; SE 0.11) and problem-solving (delta = 0.84; SE = 13) criteria" (p. 369). They also referred to the Purdue Creativity Program, along with the CPS, as "the more successful creativity training programs currently available" (p. 383).

Rose and Lin's (1984) meta-analysis only included three studies that used the PCTP and they didn't fare well. The PCTP was the second poorest performing classification, out of the six groupings they analyzed, with an average effect size of 0.33, accounting for only 11% of the variance in scores. However, when looking at the effects on the figural tests, the average effect size was 0.54, accounting for 29% of the variation. This is a larger effect size for figural scores than Rose and Lin found in any of the other groupings.

2.1.5.1.5 The Productive Thinking Program

The Productive Thinking Program (PTP) was developed in 1966 by Crutchfield, Covington and Davies. It is aimed at developing creative problem-solving abilities and related attitudes in fifth and sixth-grade students and consists of 16 lessons. Each lesson presents a mystery to be solved and follows Jim and Lila Cannon as they learn to become detectives under the tutelage of their Uncle John, a science teacher whose sideline is being a detective. Uncle John goes by the name of Mr Search (Treffinger & Ripple, 1971).

Torrance (Torrance, 1972b) grouped the PTP with the Purdue Creativity Program and the Myers Torrance Ideabooks and found that 18 of 25 studies reported a successful outcome. In this case, success was defined as follows:

> … a score of 1 was awarded if all the measured objectives of the experiment were attained. If the experiment had a single objective, such as increasing the degree of originality of thinking, a score of 1 was still assigned. However, if data were presented for fluency, flexibility, originality, and elaboration and the only statistically significant gain over the control group was in originality, a score of .25 was awarded. If 10 of 20 tests of significance reached the .05 level of confidence, a score of .50 was awarded. (p. 117-8)

Eight of the studies used the PTP. Of these, three resulted in no significant improvements over control groups, and two were rated as only partially successful. The partially successful studies showed significant differences in TTCT fluency and originality, but not flexibility or elaboration.

Rose and Lin's (Rose & Lin, 1984) meta-analysis included five studies employing the PTP. This was the worst performing group of the six groupings they analyzed, with an average effect size of 0.12. These studies showed a lack of significant improvement across all dimensions; verbal and figural; fluency, flexibility, originality, and elaboration. They even showed small negative average effect sizes for verbal fluency and flexibility – although not significant.

As with the Purdue Creativity Program, Scott, Leritz, and Mumford (Scott et al., 2004) did not present their meta-analysis in a way that summarised the results of individual programs. However, they did categorize the Productive Thinking Program as a divergent thinking program, so the same comments apply as in the last section. The bottom line is that divergent thinking programs had an average effect size of 0.74.

2.1.5.1.6 TRIZ

"The term 'TRIZ' comes from the Russian phrase teorija rezhenija izobretatelskih zadach, which means the 'theory of inventive problem solving.'" (Rantanen & Domb, 2008, p. 1) TRIZ was developed in the 1940s by Genrich Altshuller while he served in the Soviet Navy patent department. By analyzing thousands of patents, Altshuller came up with 40 principles that are intended to provide an objective, repeatable, engineering approach to innovation (Puccio & Cabra, 2010). TRIZ has evolved over the years and now, in addition to the 40 principles, it also includes 76 standard solutions, evolutionary patterns, ideal final results, and a contradiction matrix (Birdi, Leach, & Magadley, 2012). While TRIZ has been widely used in organizations, there is little research on the tools as a creativity enhancement method (Puccio & Cabra, 2010). However, Birdi, Leach, & Magadley (2012) did find that 140 engineers who took a one-day TRIZ workshop increased their motivation to innovate, improved their creative problem-solving skills, increased their idea generation at work, and showed improvement in their ideas being implemented, all compared to a control group and over an extended time period. In addition, expert ratings found that the trainee's ideas were more original, useful and persuasive.

2.1.5.1.7 Other Cognitive Approaches

Lesser-Known Cognitive Approaches There are many other lesser-known programs and courses that rely mostly on direct cognitive methods. Many are variations of the programs discussed in the previous sections or combinations of them. Some are widely available. Others are unique, one-off programs available only in one location, or from one instructor. These programs span the range of effectiveness illustrated by the programs discussed in the previous sections; from not effective, like many of the implementations of the PTP that were studied, to quite effective, like many of the implementations of the CPS program that were studied (Rose & Lin, 1984; Scott et al., 2004; Torrance, 1972b).

de Bono Thinking On the other end of the spectrum are some very popular programs that have been included in this 'others' category because of a lack of research literature. Edward de Bono's Lateral Thinking and Parallel Thinking – along with CoRT and Six Thinking Hats, which are methods for implementing his two thinking methodologies – have achieved great commercial success, with little or no research being done on their effectiveness. Sternberg and Lubart (Sternberg & Lubart, 1999) criticize Edward de Bono and others[11] for being primarily concerned with developing a creativity-enhancement program, while only being secondarily concerned with understanding it, and not at all concerned with testing its validity.

de Bono has written 57 books, mostly on thinking. Schools from over 20 countries have included his thinking tools in their curriculum. Yet Mosely (Moseley et al., 2005) states that "There is sparse research evidence to show that generalized improvements in thinking performance can be attributed to training in the use of CoRT or [Six]Thinking Hats tools."

Cognitive Modelling Gist (1989) studied the use of cognitive modelling as a method to enhance creativity. Cognitive modelling is similar to behavioural modelling – from Bandura's Social Learning Theory – but rather than visual observation of the behaviours of a model performing a task, cognitive modelling involves "a process of attending (or 'listening') to one's thoughts as one performs an activity and utilizing self-instructional thoughts (or 'statements') to guide performance" (p. 788). Meichenbaum, (as cited in Gist, 1989) found support for the use of cognitive modelling in improving the

[11] Including Osborn, Gordon, Adams and Oech.

creativity of college students. Gist's study found that "The superiority of a training method based on cognitive modeling was impressive" and "cognitive modeling training enhanced self-efficacy" (p. 802).

2.1.5.2 Non-Cognitive Approaches

2.1.5.2.1 Attitude

Basadur has examined five attitude scales: Preference for Active Divergence, Preference for Avoiding Premature Convergence, Valuing New Ideas, Creative Individual Stereotypes, and Too Busy for New Ideas. According to Basadur, Taggar and Pringle (1999) "unless attitudes toward divergent thinking are positive or become positive, training in creative problem solving involving divergent thinking is not likely to result in changes in behaviour back on the job" (p. 78). Basadur has shown that changes in attitude are a good predictor of gains from creativity training.

2.1.5.2.2 Flow

In discussing 'flow' – "the kind of feeling that an Olympic athlete may have when running her personal best, or a poet may have when turning a perfect phrase" – and its relationship to creativity, Csikszentmihalyi (1996) observes that:

> … one obvious way to enhance creativity is to bring as much as possible of the flow experience into the various domains. It is exhilarating to build culture—to be an artist, a scientist, a thinker, or a doer. All too often, however, the joy of discovery fails to be communicated to young people, who turn instead to passive entertainment. But consuming culture is never as rewarding as producing it. If it

were only possible to transmit the excitement of the people we interviewed to the next generation, there is no doubt that creativity would blossom. (p. 342)

This view seems to suggest that another form of modelling is possible, other than the cognitive modelling discussed in the previous section. While observing creative people at work may not be conducive to enhancing creativity, there may be value in learning about the thought processes and emotions of creative individuals.

2.1.5.2.3 Self-Statement Modification

Self-statement Modification (SSM) is a form of cognitive behaviour modification and has been successfully applied by Meichenbaum (1975) to creativity enhancement. While Meichenbaum's study only included 21 subjects, the self-instructional training group showed significant increases in flexibility and originality compared to a control group and to a group who applied Gendlin's focusing[12].

In psychology, SSM is considered a cognitive approach. However, from the perspective of creativity enhancement, it should be viewed as a behavioural approach associated with attitudes regarding self, creativity, and the relationship between the two. Hence this method's location here, under non-cognitive, rather than under cognitive approaches.

---

[12] "Gendlin (1969) reports that the ability to focus directly on 'preverbalized felt experiencing' does correlate with creativity" (Meichenbaum, 1975, p. 133).

2.1.5.2.4 Domain Knowledge

Amabile (1996) argues that no creativity will take place without some level of knowledge and skill in a given domain. Simonton (1999b) takes this argument a step further, noting that virtually all eminent creators display curiosity outside of their primary domain, giving rise to the concept of 'T' shaped domain knowledge (depth of knowledge and experience in one domain, with breadth of knowledge across many domains) and its positive relationship to creativity. Therefore, it appears that creativity can be enhanced by developing particular expertise while being well informed in a variety of areas.

2.1.5.2.5 Metacognitive

Metacognition is, literally, cognition about cognition. Furthermore, cognition can be defined as "the attention of working memory, producing and comprehending language, learning, reasoning, problem solving, and decision making" (C T I Reviews, 2016). Thus, metacognition can be thought of (pun intended :) as thinking about thinking, thinking about learning, or thinking about problem-solving. As pointed out by Kozbelt, Beghetto, & Runco (2010) "Metacognitive processes are also frequently tied to creative thinking" (p. 32). They note that tactical thinking is metacognitive, thus most, if not all, of the programs discussed in the cognitive approaches section above, have a metacognitive aspect to them.

Much like SSM, metacognition has been included here, under non-cognitive approaches, because of its potential behavioural and attitudinal effects. Scott, Leritz, & Mumford (2004), in their meta-analysis, concluded that "informing people about the nature of creativity and strategies for creative thinking is an effective, and perhaps necessary, component of creativity" (p. 380). Perhaps more important is the potential for metacognition to positively impact self-efficacy. Zimmerman (1995) defines self-efficacy as "a context related judgment of personal ability to organize and execute a course of action to attain designated levels of performance" (p. 218). Giving people the tools to be successfully creative should, as Bandura (1977) notes, give them the "conviction that [they] can successfully execute the behaviour required to produce the outcomes" (p.193).

2.1.5.2.6 Motivation

Amabile (Amabile, 1996) has written extensively about the effects of motivation on creativity. She concludes that intrinsic motivation is conducive to creativity and that extrinsic motivation usually, but not always, has a negative effect. Amabile notes that the following can have a negative impact on creativity: expected reward, expected evaluation, peer pressure, surveillance, and constrained choice. These factors can all be seen to potentially affect creativity through an effect on motivation. Conversely, Amabile sees choice, control, a supportive environment, a stimulating physical environment, freedom, and play as potential approaches to enhancing creativity.

2.1.5.2.7 Meditation

Fink and Neuberger (2006) found that creative problem-solving tasks produce "synchronization of alpha activity, presumably reflecting a reduced state of active information processing in the underlying neuronal networks… [which] stands in clear contrast to the phenomenon of alpha desynchronization that is usually observed during the performance of conventional cognitive tasks, i.e. tasks of a rather convergent type" (p. 51-52). Since meditation is known to produce alpha synchronization, it has long been hypothesized that meditation could increase creativity. However, Krampen (1997), in his literature review, found inconsistent effects from long-term relaxation or meditation programs. On the other hand, Krampen's study of the short-term effects of relaxation exercises showed consistent, significant improvements in both divergent and convergent thinking.

Ostafin & Kassman's (2012) two studies, of a total of 157 participants, found that mindfulness training improved insight, but not non-insight, problem-solving.

2.1.5.3 Summary

The obvious problem with attempts to enhance creativity is that without a clear definition and an accepted and reliable means of assessing creativity, exactly what is being enhanced is not clear. This dissertation presents a definition and a model of creativity that can address this problem.

2.2 Theories of Product Innovation and Their Relationships to Creativity Theories

Creativity and innovation are inextricably linked, as is seen in many of the definitions used to define the two constructs (see the next paragraph, for example). Therefore, a broad review of the topic of creativity requires at least some review of the topic of innovation. Once again, the topic is too large to present a thorough review, so this section will primarily focus on an area that has been recognized as being a complex adaptive process – the diffusion of innovation (Everett M Rogers, Medina, Rivera, & Wiley, 2005).

Sir Ken Robinson (2011) defines the interrelated terms – imagination, creativity, and innovation as follows: *imagination*… is the process of bringing to mind things that are not present to our senses; *creativity*… is the process of developing original ideas that have value, and *innovation*… is the process of putting new ideas into practice" (p. 2-3). These definitions serve as a useful backdrop to this section on product innovation.

New, creative ideas are meant to replace older ideas with something better (note the *value* part of the definition of creativity). So, you might think that creative ideas would spread and be adopted as quickly as information about them can travel. Or at least as fast a new product can be manufactured and shipped. Of course, we know that is not the case. Even the internet has taken over 2 decades to reach its current penetration rate of 88.5% in The U.S. and Canada and 46.1% worldwide ("Internet Users by Country (2016)," 2016; "Number of Internet Users (2016)," 2016). Electricity took about 6 decades to reach virtually 100% penetration. The automobile took over 90 years to reach its maximum penetration rate of 92%, and now shows signs of dropping (Kahan, 2012).

Why? What causes these differences in the rate and degree of adoption? Many innovators think that their innovative ideas or products will sell themselves. If I build a better mousetrap, why *won't* the world beat a path to my door? This section on the diffusion of innovation will present various attempts at answering these questions.

2.2.1 Diffusion of Innovations According to Rogers[13]

The simple S curve – a seemingly simple concept -who would have known it holds a wealth of information? Who would have known it has a very broad application? Apparently, Everett Rogers did. At least, he did by the time he finished his dissertation in 1957. Rogers wasn't the first to show that the diffusion of innovations follows an S-curve: starting out slowly, accelerating, and reaching an inflection point where the rate of diffusion begins to decelerate. Rogers was, however, the first to argue that diffusion is a general process that explains social change of any type.

Following his PhD, Rogers went on to write *the* book on the diffusion of innovation, with the publication of *Diffusion of Innovations* in 1962. For four decades Rogers remained committed to the field, continuing to refine and expand the theory while collecting further evidence. Just one year prior to his death in 2004, the fifth edition of his book was published.

Rogers defines innovation as "an idea, practice, or object that is perceived as new by an individual or another unit of adoption" (p. xx). Innovations cause uncertainty. It is not at first known if the new idea is better than the status quo. Will it perform better, faster, more efficiently, with fewer risks, or with greater risks? Will it cause unintended consequences? Early adopters – a term coined by Rogers – are motivated to find out more. Once these early

[13] The content for much of this section was derived from Rogers' (2003) *Diffusion of Innovations*. Page references in this section are to this book, unless otherwise noted.

adopters make a favourable decision and start using the innovation, information about their experience is passed on through their social network, and the innovation continues its *diffusion*. "Diffusion is the process in which an innovation is communicated through certain channels over time among the members of a social system. It is a special type of communication, in that the messages are concerned with new ideas" (p. 5). "The diffusion of innovations is essentially a social process in which subjectively perceived information about a new idea is communicated from person to person" (p. xx).

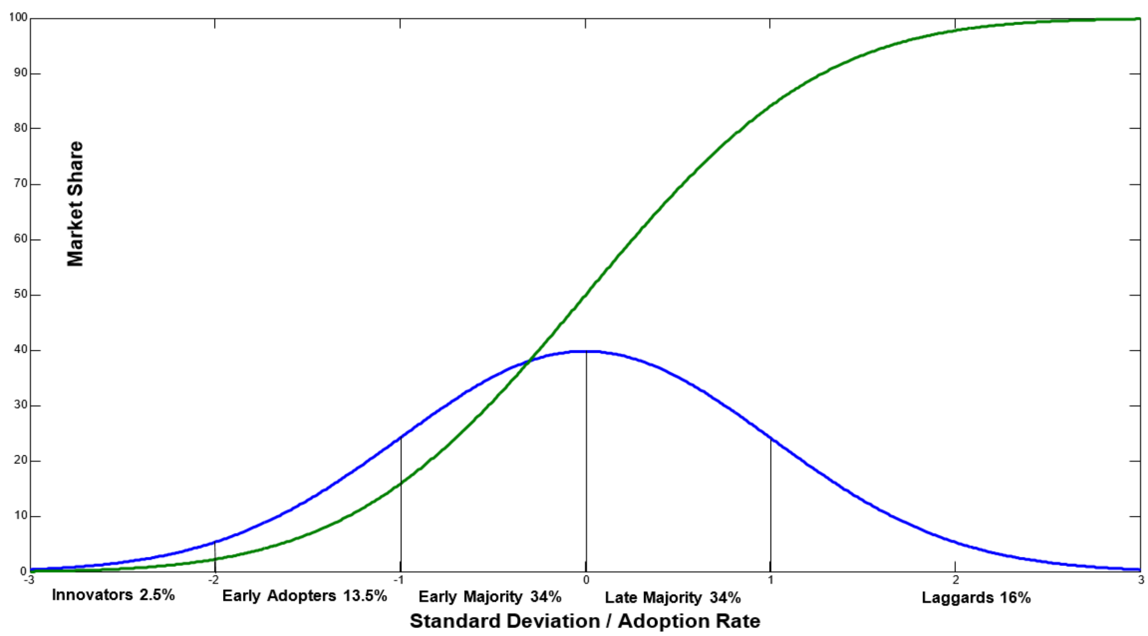


Figure 2: Normal and Cumulative Distribution Functions

2.2.1.1 Dvorak Example

The Dvorak keyboard provides a good example of what Rogers refers to as *nondiffusion*. The QWERTY keyboard that most of us are quite familiar with was invented in the early 1870s to slow down typists. If two neighbouring keys of one of these early typewriters were pressed in rapid succession, the typebars[14] would often jam. The QWERTY keyboard layout was an innovation that minimized this jamming problem by placing commonly used letter pairs well away from each other. The innovation sped up typing, by minimizing jams, but it also slowed down how fast someone could type when the typebars didn't jam.

By the early 1900s typewriters were more efficient, and the QWERTY keyboard layout was no longer necessary to reduce jamming. It was now possible to use a more efficient layout. So in 1932, Professor August Dvorak used time and motion studies to develop what was intended to be the most efficient layout possible. Reports showed a 30-50% increase in productivity with the Dvorak keyboard (Parkinson, 1972), while only requiring about a week of practice to switch from the QWERTY keyboard (Everett M. Rogers, 2003). But it has failed to catch on. After 30 years of trying to introduce his keyboard, Dvorak reportedly said "I'm tired of trying to do something worthwhile for the human race… they simply don't want to change!" (Parkinson, 1972). This seems to be an all-too-often heard lament of the frustrated inventor, as a result of a technically superior product losing out to a market incumbent.

2.2.1.2 Change and Risk

Why won't people switch? There are many factors that affect the diffusion of an innovation, but most can be related to risk. The newness (novelty or originality, from a

---

[14] A typebar is metal bar with a raised letter on it, which rises up to strike an ink ribbon when a key is pressed, leaving ink on the paper in the form of the letter.

creativity perspective) of an innovation means there is some degree of risk or uncertainty associated with implementing the innovation.

Innovation always requires change. Change from the status quo to a new way of doing things. And change requires an investment. If not an investment in the cost of a new product, then at least an investment of time in learning something new, or an investment of time to investigate the claims of this new innovation. After all, if you were 100% certain that a new process would cost nothing to implement, lead to lower future costs, lead to better outcomes, with no negative impacts, you would certainly adopt this new process. But early adopters can never be certain that an innovation will prove to be an improvement over the status quo while causing no negative side effects.

Side effects of implementing an innovation can be particularly difficult to foresee. As Rosen, Rosen, Kineman, and Nadin (2012) note: "almost every therapeutic agent, as well as most diagnostic agents, create them [side-effects]." Many examples can be found in most aspects of human endeavour, including medicine, technology, and public policy.

Thalidomide was a sedative that was marketed in the late 1950s as a means to reduce morning sickness in pregnant women. It led to many thousands of birth defects and a mortality rate greater than 50% in those babies with the birth defects. In the 1700s, rabbits were introduced to Australia for food and for hunting. They became an invasive species, causing millions of dollars of damage to crops and livestock;[15] estimates range from $113 - 600 million (Technologies, 2016). The Ohio Turnpike was built without curves in order to avoid accidents. The unfortunate side effect was the discovery of road hypnosis (Rosen et

[15] By outcompeting livestock for food during drought periods.

al., 2012). The meltdown at Chernobyl occurred during a test of enhanced safety procedures (Tenner, 1996).

Tenner gives several examples of side effects in his 2011 TED Talk titled *Unintended Consequences* (2011). He claims the domestication of grain led to worse nutrition, shorter lifespans and a much higher degree of inequality. Boat builders, after learning a harsh lesson from the Titanic, ensured boats had enough lifeboats on them. Then, in 1915, the Eastland capsized. 841 people died. More people than died on the Titanic. One of the contributing causes were the extra lifeboats, which made the already unstable ship more unstable. In a second example, the bacteria that causes Legionnaires disease thrives in water at a precise temperature in heating, ventilation and air conditioning (HVAC) systems. Once this was discovered, in 1976, bactericide was introduced into the water in HVAC systems. Tin was included in the bactericide. By the early 1980s, it was discovered that the tin from the bactericide added to the water in HVAC systems was getting into computer tape drive systems, leading to early failures of the systems.

And, if our history of unforeseen side effects isn't bad enough, Tenner notes how our technological capabilities are expanding geometrically, but our ability to model the behaviour of technological systems, and thereby foresee consequences, has only been expanding arithmetically, leading to a rapidly expanding gap. On the other hand, Tenner notes that calamities often lead to positive advances. Two historians of business, Brent Goldfarb and David Kirsch, have shown that the greatest decade for major technological innovations was during the great depression. "Depressions, and all kinds of other unfortunate events, can have a paradoxically stimulating effect on creativity" (Tenner, 2011,12:05). Tenner concludes with "Chaos happens; let's make better use of it" (Tenner, 2011, 15:47).

2.2.1.3 Diffusion of Innovations: Overview

Rogers noted four main elements of the diffusion process: the innovation, communication channels, time, and the social system (note the relationship to his definition of diffusion quoted earlier[16]). He also identified five characteristics of innovations that explain differences in rates of adoption: relative advantage, compatibility, complexity, triability, and observability. Each of these characteristics either has an effect on the perceived level of risk or provides an incentive for accepting the risk. The five main steps Rogers identified in the innovation-decision process are knowledge acquisition, persuasion, decision, implementation, and confirmation. Finally, Rogers broke the diffusion curve into five parts and painted a picture of the adopters that can be expected at each stage: innovators, early adopters, early majority, late majority, and laggards. The following sections will briefly discuss the four main elements, the five characteristics, the five steps and the five stages and types of adopters.

2.2.1.4 Adopter Types and Stages

The adopter types Rogers defines coincide with where they are situated, temporally, on the diffusion of innovation S-curve. They also relate to their positioning within a social system and their degree of innovativeness[17]. The five types he defines are innovators, early

---

[16] Reproduced here for convince: "Diffusion is the process in which an innovation is communicated through certain channels over time among the members of a social system. It is a special type of communication, in that the messages are concerned with new ideas" (p. 5).

[17] Rogers defines innovativeness as "the degree to which and individual or other unit of adoption is relatively earlier in adopting new ideas than other members of a system" (p. 475).

adopters, early majority, late majority, and laggards (see Figure 2). In addition, Rogers defines a change agent as "an individual who influences client's innovation-decisions in a direction deemed desirable by a change agency" (p. 473).

Change Agents are, most commonly, sales professionals, agricultural extension service agents, public health workers, or consultants. Change agents are needed because of the social and technical gulf between the change agency and their target clients. The change agent's role is to bridge that gulf. However, they also come from a different social system and often have a different level of technical knowledge and ability compared to their clients. For these reasons, the role of the change agent should be to disseminate information and only attempt to influence innovators and early adopters – ideally through risk reduction approaches which seek to increase triability, observability and compatibility while reducing perceived complexity (a discussion of these terms will be found in the following pages).

Innovators typically possess above average intelligence, insatiable curiosity and have a high tolerance for uncertainty. Their social relationships are often more cosmopolitan. However, they may have a dearth of local relationships. They are typically venturesome and risk-tolerant with a keen interest in new ideas. They also frequently have sufficient financial means to be able to absorb losses from innovations that don't work out. To the more conservative majority, they may appear foolhardy or odd.

Early Adopters share many of the traits of Innovators but to a lesser degree. The main difference between the two categories is their local network. Early adopters have an extensive local network. They are opinion leaders, respected by their peers. These are the ones to win over if an innovation is to spread to the early majority and become self-sustaining.

The Early Majority are slower and more deliberate in their decision-making process. They are more risk averse than innovators and early adopters, but they still adopt before the majority of the population. They have an extensive local network but are not considered opinion leaders.

The Late Majority approach innovations with caution and skepticism. They may eventually adopt for economic reasons, or due to peer pressure. By the time they adopt, the innovation may no longer be perceived as an innovation. The Late Adopters may just be conforming to the new normal.

Laggards are the last to adopt. Laggards often resist change and are suspicious of innovations and change agents. They typically have very little opinion leadership. On the other hand, their resistance to innovations may be entirely rational from an economic point of view. Their economic position may necessitate their caution.

The diffusion process often proceeds with a change agent informing innovators and early adopters about the innovation. Change agents work with innovators to increase triability, observability, and compatibility while reducing perceived complexity. Innovators take the lead and try the innovation. Early adopters may be informed by a change agent, but are ultimately most often influenced to adopt by an innovator. The early majority are influenced to adopt by early adopters (not innovators, who do not have as extensive a network as early adopters and may be viewed as a fringe element by the more conservative majority). The late majority adopt after virtually all risks are removed and the benefits of adopting are clear. The late majority, in fact, end up surrounded by evidence of the value of the innovation. The laggards adopt when the price drops even further, when switching becomes easier than sticking with the old way, or when social pressure to conform to the new normal mounts. Still others never switch. Rogers includes those who never adopt an innovation as laggards. Perhaps a separate category called holdouts, or non-adopters would be useful.

2.2.1.5 Four Elements of the Diffusion Process

Within Rogers' definition of diffusion are the four elements of the diffusion process: diffusion is the process by which an *innovation* is *communicated* through certain *channels* over *time* among the members of a *social system*. Each of those elements will be discussed next.

Communication Channels: Rogers discusses two main communications channels: mass media and interpersonal. That is, one-to-many and one-to-one communication. He suggests that mass media is typically most effective at generating awareness and disseminating knowledge, but interpersonal communications are usually required to persuade an individual to accept a new idea.

Most people rely on the subjective evaluations of other people like themselves who have already adopted the innovation. Facts, figures, and scientific studies won't persuade the early majority, late majority, or laggards. People will persuade them. The more like them those people are, the more likely the persuasion is to happen. Even early adopters are more likely to be persuaded by the experiences of an innovator who has adopted the innovation, than by the facts presented by a change agent.

Rogers also notes that "interactive communication via the Internet has become important for the diffusion of certain innovations in recent decades" (p. 18). Yet in 2003, when the 5th edition of Roger's book was written, the real interactivity of Web 2.0 had barely begun. At the time, web 2.0 was, for the most part, just a discussion of what the internet could be in the future. Now that we have all of the capabilities envisaged for Web 2.0 – user-generated content, interoperability, collaboration, content sharing, virtual communities, many-to-many communication channels, and more, – the internet blurs the lines between mass media and interpersonal communications. The internet reveals this perceived dichotomy for the continuum it always has been. It seems that the effect of the internet on communication, and the resultant effect on the diffusion of innovation, has not been fully explored.

Time plays a role in the diffusion of innovations in three ways. First, it takes time for each individual to go through the innovation-decision process (see the subsequent section titled *Five Steps in the Innovation-Decision Process*). Secondly, the relative earliness/lateness in which individuals adopt is viewed across time. Finally, the innovation's rate of adoption in a system is an important factor in diffusion studies and is usually measured as the number of people, or percentage of people, who adopt an innovation over a certain time period.

The Social System Rogers defines a social system as "a set of interrelated units that are engaged in joint problem-solving to accomplish a common goal" (p. 23). The social structure affects the diffusion of any particular innovation. Rogers goes on to discuss the formal and informal structures within a social system.[18] Formal structures include things like the reporting relationship defined in an organizational chart or the complaint escalation policy of a government department. Informal structures include interpersonal communication networks – frequently being homophilous cliques. People who have more in common tend to communicate more often, aiding in the diffusion of innovations. Thus, the informal system has more impact on diffusion.

---

[18] There is an interesting parallel here between Rogers' discussion of formal versus informal social systems and what Stacey (1996), in *Complexity and Creativity in Organizations* calls the formal and shadow systems that operate within organizations.

Diffusion researchers have identified opinion leadership as one of the most important aspects of the social system. Within the adopter types, the opinion leaders are the early adopters, followed by the early majority and the late majority. The laggards have little to no opinion leadership, and the innovators could even be viewed as having negative opinion leadership. "The most innovative member of a system is very often perceived as a deviant from the social system and is accorded a status of low credibility by the average members of the system" (p. 26).

Laggards have no opinion leadership because there is no one to come after them. There is no one left to adopt who could use the opinion of someone who has more in common with them than with the early adopters. The further apart people are on the diffusion curve, the less they have in common. But the closer they are, the more they have in common – and that is part of the reason the diffusion process works; adopter types are a continuum with everyone having a great deal in common with those next to themselves on the continuum. Instead of being shunned by everyone, some early adopters are open-minded and curious enough to pay attention to what the innovators are doing. And since the early adopters maintain a broad network of connections, they manage to stay in contact with some of the 'deviant' members of the social system.

The Innovation The innovation element of the diffusion process is key and, therefore, will be addressed in its own section.

2.2.1.6 Five Characteristics of the Innovation

Relative advantage is the degree to which an innovation is perceived as better than the alternatives. The alternative is most often the status quo but may include other competing innovations. The relative advantage is often thought of in economic terms, but it may also be an ecological, social prestige, satisfaction, or convenience advantage. All else being equal, the greater the relative advantage, the faster the rate of diffusion of the innovation. Greater perceived advantage helps to overcome the risk associated with an innovation adoption decision. The advantage is the reward in a risk/reward decision.

Compatibility refers to the degree to which the innovation fits within existing social, value, and support systems. For example, one of the issues associated with electric vehicles competing with gas vehicles is that an extensive network of gas stations has been built up over the last century. There are comparatively very few electric vehicle charging stations. Hybrid vehicles were developed to increase compatibility with the existing infrastructure and provide a bridge to a future that supports fully electric vehicles. Greater compatibility reduces the risk of an innovation adoption decision. All else being equal, greater compatibility will yield a faster rate of diffusion of the innovation. Highly innovative ideas may require bridging strategies, such as the hybrid vehicle, to enable adoption.

Complexity is the perceived difficulty associated with learning, understanding, using and maintaining an innovation. New ideas that are simpler to understand are adopted more quickly than those that require the development of new knowledge, skills, or abilities. One of the impediments to the adoption of the Dvorak keyboard is thought to be the fact that it requires the adopter to develop a new skill. All else being equal, innovations that are perceived as less complex will have a faster rate of adoption. Complexity increases the perceived risk of an innovation.

Triability refers to the potential for an innovation to be tried and tested on a limited basis. Free samples are often used by companies to improve the triability of a new product. Software is often provided free for the first month or more. Even the original Blackberry was given to executives to use for free for a month. Users loved them so much that they were almost never given back. The evaluators were quickly converted to customers (McNish & Silcoff, 2015). Triability reduces the risk associated with the adoption of an innovation. Thus, all else being equal, more triable innovations will have a higher rate of adoption.

Observability is the degree to which the use, implementation, and/or results of an innovation can be readily seen by others. Such observability stimulates discussion and reduces the risk for subsequent adopters. The result of high-observability can be seen in adoption clusters, such as the clustering of residential solar panels in some neighbourhoods. Higher observability generally leads to higher diffusion rates.

2.2.1.7 Five Steps in the Innovation-Decision Process

Rogers breaks the innovation decision process down into five main steps: knowledge, persuasion, decision, implementation and confirmation.

Knowledge is gained when an individual learns of the existence of an innovation. Further knowledge is accumulated when the individual learns more details about the features, benefits, costs and risks associated with an innovation. Knowledge may be gained from mass media, a change agent, someone within the social system, observation, or by trying out an innovation. As knowledge seeking continues, an individual is overcoming uncertainty and reducing the risk associated with adoption.

Persuasion is the process of an individual forming a favourable or unfavourable opinion about an innovation. This process begins during the knowledge gathering process, but concludes, for most, through learning of the subjective evaluations of near-peers and opinion leaders.

Decision "occurs when an individual engages in activities that lead to a choice to adopt or reject the innovation" (p. 20).

Implementation takes place when an innovation is put into full practice, that is, no longer on a trial basis.

Confirmation may occur on a continuous basis as an adopter seeks reinforcement that the correct decision was made. If confirmation does not take place, the implementation may be reversed and the innovation rejected.

2.2.1.8 Criticism

Moore (1991) argues that the diffusion of innovations theory views adoption as a relatively smooth function over time, while it is anything but. In particular, he sees a large gap between early adopters and the early majority (see the next section *Crossing the Chasm* for more on this).

Rogers sorts criticisms of the theory into five categories: pro-innovation bias, individual-blame bias, recall problem, causality, and issues of equality.

The pro-innovation bias in diffusion research is the implicit or explicit assumption that the innovation should be adopted by all members of the target group, that more rapid diffusion is better, and that the innovation should not be re-invented (changed), or rejected. Rogers claims this bias has led researchers to avoid studies looking at the ignorance of innovations and to underemphasize rejection, discontinuance, and reinvention in research.

Because diffusion research tends to take the point of view of the change agency, the research tends to lean toward individual blame, rather than system blame. One example is the communication campaigns of the 1960s aimed at reducing motor vehicle accidents, which targeted, primarily, speeding and the use of seatbelts. Ralf Nader's (Nader, 1965) book *Unsafe at Any Speed* changed the narrative to focus more on system blame. That is, unsafe cars and highways were implicated instead of drivers. Innovation research often blames the late adopter for being slower than they 'should be' in adopting the innovation. They are thus labelled "traditionally resistant to change" or "irrational" (p. 121). A closer analysis may reveal that the innovation is not appropriate, given their particular circumstances. Not adopting may be the most rational decision for them. See the laggard farmer description in the following *Links to Creativity* section for an example of this.

Most diffusion research is completed after-the-fact, once the diffusion of an innovation is complete, or nearly so. Thus, the research is dependent on surveys or questionnaires where the respondent is asked to recall a specific time when they started using an innovation. This, of course, leads to inaccuracies based on inaccurate recollections. With more and more transactions having a digitized 'paper trail' these days, this shortcoming of diffusion research is becoming less of a problem.

Factors such as wealth, education, or cosmopoliteness may be causes, or effects, of innovativeness. Or there may be a more complicated reciprocal causality over time. Or there may be an outside factor, not considered, which causes both innovativeness and the other factors listed. While diffusion studies may show correlations, they are generally not designed to determine causality.

Rogers claims that diffusion researchers have ignored the consequences of innovations. In particular, they have not looked at what appears to be the frequently inequitable distribution of the benefits of innovation. "When the issue of inequality has been investigated, it has been shown that the diffusion of innovations often widens the socio-economic gap…" (p.130). This is particularity relevant now, as the perceived and actual inequality in wealth distribution seems to be grabbing mindshare across many forms of media. Thomas Piketty's (Piketty, 2014) *Capital in the Twenty-First Century* has done much to help maintain and intensify this focus. Rogers suggests that change agents take deliberate steps to minimize or reverse the inequalities of the diffusion of innovations and that researchers pay more attention to this aspect of the field.

2.2.1.9 Links to Creativity

One of the more interesting links to creativity exposed by *The Diffusion of Innovations* is the attributes of the innovator, as described by Rogers, and of the creative personality type described by many creativity researchers (see, for example, Feist, 1998, 2010; Sawyer, 2012; Weisberg, 2006). What is not so readily apparent is the potential link between some of the holdouts (who Rogers labelled as laggards) and the creative personality type.

Rogers described one holdout he came across while doing his dissertation research, who did not adopt any of the innovations recommended by agricultural extension service agents. "He claimed they killed the earthworms and songbirds in his fields." Rogers labelled him as a laggard at the time. He now recognizes that he would have been an innovator in the organic food movement. If we change from Rogers' definition of innovativeness to using the common definition of creativity, this example provides an interesting case study on what is useful, who is creative, and when.

To the majority of farmers in the 1950s and 60s the new chemical fertilizers, pesticides, and herbicides were very useful. They reduced work, increased yields and increased profits. What could be more useful than that? To a small minority, these so-called creative innovations were not useful because killing earthworms and songbirds was not compatible with the values of this small minority. These individuals, by many accounts, (see, for example, Feist, 1998, 2010; Sawyer, 2012; Weisberg, 2006) would be much more likely to fit the creative personality profile than the majority of those who adopted the innovations.

It seems that when almost everyone has adopted an innovation – when it is well past being considered new – the only people left who have not adopted the innovation are either those who fit Rogers' definition of a laggard, or those who are truly creative – but too original or novel in their thinking to be viewed as such at the time. These are the ones who should be watched, interviewed, and listened to, to find the next innovation. But the true creatives, it seems – the innovators, and some portion of the laggards – are generally ignored. Much like creative ideas are often filtered out by our brains' executive function, and much like truly creative ideas are shunned in brainstorming sessions because it seems so easy to point out the myriad ways in which they won't work. By the time the early majority are adopting an innovation, some people would no longer think of it as innovative. The true innovators have moved on to something else – and some of the laggards will never adopt the 'innovation' because they're thinking further into the future.

2.2.2 Crossing the Chasm

Roughly thirty years after Rogers first wrote *Diffusion of Innovations*, Geoffrey Moore noticed a challenge many companies had reaching the early majority, after successfully marketing their products to early adopters. While he praised the value of the diffusion of innovations theory – or the technology adoption lifecycle, as he refers to it – he argues that its main flaw is in assuming smooth, gentle slopes.

Moore (1991, 2014) also notes the difference between continuous innovation and discontinuous innovation. As he explains it, "continuous innovation refers to the normal upgrading of products that does not require us to change behaviour" while discontinuous innovations "require us to change our current mode of behaviour or to modify other products and services we rely on" (Moore, 2002, p. 10). Moore contends that the introduction of discontinuous innovations is relatively rare for traditional industries, but routine for "high-tech" businesses; therefore, understanding the technology adoption lifecycle is crucial to marketing high-tech products.

Rogers (Everett M. Rogers, 2003) argues that innovativeness – the variable along the x-axis of Figure 2– is a continuous variable and therefore there cannot be any gaps. This argument may make sense theoretically, but in practice, other factors come into play.

My own experience with the technology adoption lifecycle, which took place throughout the 1990s, suggests that the chasm between early adopters and the early majority often does exist. However, crossing it is more a matter of good timing than of good marketing. Thus, navigating the technology adoption life-cycle is more of a strategic issue than a marketing issue.

In the early 1990s Computer Based Training (CBT), as it was called at the time, was only popular in the Information Technology (IT) sector.[19] This was a result of several factors. IT workers were obviously comfortable with computers, they typically had their own computer on their desks at work, and they worked in a field that required constant learning to stay on top of new programming languages, standards, protocols, and operating systems. Within many companies, IT workers were geographically dispersed, and in consulting companies, they often had 'downtime' between assignments. All of these factors meant that CBT made sense for the IT industry at a time when it was not useful to other industries.

The next major industry to adopt CBT was banking. By the mid-1990s every branch had at least one computer and every branch computer could connect to a central computer

---

[19] Technically, CBT was common in the military before it became common in IT. But, when it comes to the technology adoption life cycle and marketing technological innovations, the military is a special case.

to receive any required updates. This was a minimum requirement if computers are to be used for training. Bank employees were geographically dispersed, which makes centralized classroom-based training prohibitively expensive. Increasing regulatory and compliance requirements throughout the 1990s led to increased training needs. And the bank teller position has one of the highest turnover rates of all professions. When these factors all came together, adoption of CBT in the banking industry took place quickly. Before all these factors coincided, it didn't matter how triable and observable CBT was. Without a computer in every branch, CBT was not compatible with the banks' systems. And before there was a computer in every branch, most bank executives would have dismissed CBT as to complex for too many of their staff.

Before all of the factors noted above came together, CBT did not offer the banks a relative advantage – there was no value in adopting CBT. Therefore, there was a chasm, and all the marketing in the world would not have helped cross that chasm. However, what Moore's book does – or, more generally, what knowledge of the technology adoption lifecycle does – is help the reader determine where to look for the next adopter.

Even being armed with knowledge of the technology adoption lifecycle, however, is not always enough. In the early 2000s, one of the next major industries to adopt CBT (by this time being called Web-Based Training (WBT), Technology-Based Training (TBT), or simply Online Training) was the quick-service restaurant industry.[20] While they fit the model of a geographically dispersed workforce with high turnover and high training requirements, compatibility and complexity were seen by some as insurmountable issues. However, some

---

[20] Commonly referred to as fast-food restaurants, but many in the industry work diligently to avoid that term, due to its negative connotations.

franchises thought the relative advantage outweighed the other issues. Now, of course, online training in this industry is ubiquitous.

Moore's arguments are based on a business to business focus (Moore, 1991; Schawbel, 2015), while Rogers' theories are based on business (or organization) to consumer communication.[21] This appears to be one of the reasons Rogers sees innovativeness as a continuous variable, while Moore sees it as discontinuous, having at least one gap. However, the gap that Moore sees between the early adopters and the early majority is very similar to what Rogers describes as the slow diffusion from innovators to early adopters.

Some of the most successful products, which make for some of the most interesting diffusion case studies, follow a technology adoption cycle that begins with businesses, then expands to consumers. In this case, even within the same product, there are essentially two different adoption life cycles, one for businesses and one for consumers. Each has its early adopters, early majority, and etcetera. But the early majority in business may play the role of the early adopter for consumers, paving the way for more rapid diffusion in the consumer market.

For example, early business use of computers helped drive down their price, reduce the complexity, and increase their triability and observability. This paved the way for the adoption of computers by consumers. Before the age of the internet, companies had internal computer networks. For many companies, email became a core communication technology long before the internet, which resulted in the necessary critical mass required for email to be useful to individuals outside of business organizations. These factors are not discussed by either Rogers or Moore.

[21] If one views the farmer of the 1950s as being more consumer-like than like today's businesses.

Where do they agree? Adoption is a social process. People do what they see other people doing, particularly people whose opinion they respect, and people they have much in common with. Until a tipping point is reached, increased adoption requires more and more marketing effort. Rogers calls it reaching critical mass, after which point, adoption becomes self-sustaining. "Such peer influence usually makes the diffusion curve take off somewhere between 5 and 20 percent of cumulative adoption (the exact percentage varies from innovation to innovation, and with the network structure of the system)" (Rogers, 2003, p. 360). Interactive innovations (email, telephone, fax, social media applications – where you need others with the same technology to make the innovation worthwhile) reach critical mass due to the relative advantage increasing as adoption rates increase. For non-interactive innovations, critical mass has more to do with the social aspects of diffusion.

Crossing the Chasm's real contribution was to translate the research focus of *Diffusion of Innovations* into marketing prescriptions for the relatively new, in 1991, 'hi-tech age.' Moore points out that different marketing messages and approaches are required for each of the segments. One of the highlights, in this regard, is part of Moore's definition of a market: "the notion that part of what defines a high-tech market is the tendency of its members to reference each other when making buying decisions-- is absolutely key to successful high-tech marketing"(Moore, 1991, p. 29). This, coupled with the concept of a tipping point, highlights the value of market segmentation.[22]

[22] That is, by starting with as small a market segment as possible, it is more likely that the tipping point – that point where diffusion is self-sustaining within the market segment – can be reached. Progressively larger market segments can then be defined, with customers who fit both established and new market segments acting as a beachhead of early adopters for the new market segment.

The third edition of Moore's (2014) book does little more than update examples to make them more contemporary and add a brief appendix offering a light-weight model for digital consumer adoption. Moore calls this the four gears model. The four gears, or activities, which he claims need to be focused on to reach a tipping point – where the market itself will drive further adoption – are: acquire traffic, engage users, monetize that engagement, and enlist the faithful. This model is elaborated upon in *Inside the Tornado* (Moore, 1995). His thesis is that, before reaching the tipping point, one of the four gears will be the slowest and will be slowing down the other three. The company's resources should be focused on speeding up that slowest gear.

2.2.2.1 Links to Creativity

Moore argues for discontinuity in innovation diffusion, while Rogers argues for continuity. This is similar to the Big C / little c versus continuous-creativity discussion prevalent in creativity literature. For example, Kozbelt et al. (2010), argue for viewing creativity as a discontinuous variable, being separated into the two categories of Big C or little c. Others (Amabile, 1996, for example) argue that creativity is a continuous variable. It seems obvious that creativity exists along a continuum, and trying to force creativity into discrete boxes, such as pro c, mini c, little c, and big C, does creativity research a disservice. Similarly, while the diffusion of innovations may not exhibit nice, smooth distribution curves, there does not seem to be a sound argument for them to considered discontinuous.

The relative advantage discussed in diffusion research relates to *usefulness* or *value* in the definition of creativity. On the other hand, *novelty* – the other half of the definition of creativity – is related to perceived risk in diffusion research. The more novel a product or idea is, the more perceived risk is associated with it. Anyone involved in launching an innovative product (trying to get a product or idea to diffuse throughout the target population) should keep in mind the dual scales of creativity and their different natures. That is, while usefulness (or perceived usefulness) should be maximized, novelty needs to land in the Goldilocks zone – there needs to be enough of it, but not too much – in order to maximize diffusion.

2.2.3 The Innovator's Dilemma[23]

In yet another analysis of the S-curve, Christensen (1997) explores why some well-run companies are seemingly blind-sided by technology upstarts. Christensen (1992) claims there are limits to the technological S-curve, which many scholars have declared is the key to managing technology development strategically. The S-curve, in this case, is very closely related to the diffusion of innovations S-curve discussed in previous sections. The essential difference is in perspective. The diffusion of innovations S-curve is best interpreted as taking the point of view of the consumer. The technology S-curve can be thought of as taking the research and development department's point of view.

The concept that Christensen rails against is that the point of inflection in the technology S-curve can be used as an indicator of when new technology needs to be in place, "rising from below" to replace, or augment the current technology. He notes that the inability of a firm to anticipate competitive threats rising from below has been viewed as a failure on the part of management. Christensen's interpretation of his research is that "the

[23] The content for much of this section was derived from Christensen's (Christensen, 1997) *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail.* Page references in this section are to this book, unless otherwise noted.

widely accepted principles of good management" should not always be followed. He suggests there are times when "it is right not to listen to customers, right to invest in developing lower-performance products that promise lower margins, and right to aggressively pursue small, rather than substantial, markets" (p. xii).

Christensen's thesis rests on his differentiation between sustaining and disruptive innovations. While other scholars have differentiated innovations as incremental versus radical (or discontinuous), Christensen says sustaining technologies can be incremental, or radical. The common aspect of sustaining innovations is that they improve the performance of existing products "along the dimensions of performance that mainstream customers in major markets have historically valued" (p. xv). Disruptive technologies, on the other hand, perform worse in areas considered to be key performance indicators for the established market. But they have other features that a small, often new, market segment values. The new products are often less expensive, more convenient, smaller, and/or simpler to use.

Another key to Christensen's thesis is that technological progress, along those dimensions related to key performance indicators for the established market, is faster than the market demand for this technological progress. The result is that suppliers eventually give customers more than they ultimately need or are willing to pay for. This provides an opportunity for disruptive technologies to catch up to market demand in those areas where they originally underperformed. Once they meet market demand in those areas, they suddenly have a competitive advantage due to lower price, and the unique features that their early adopters appreciated. The concept of sustaining versus disruptive innovations is illustrated in Figure 3.

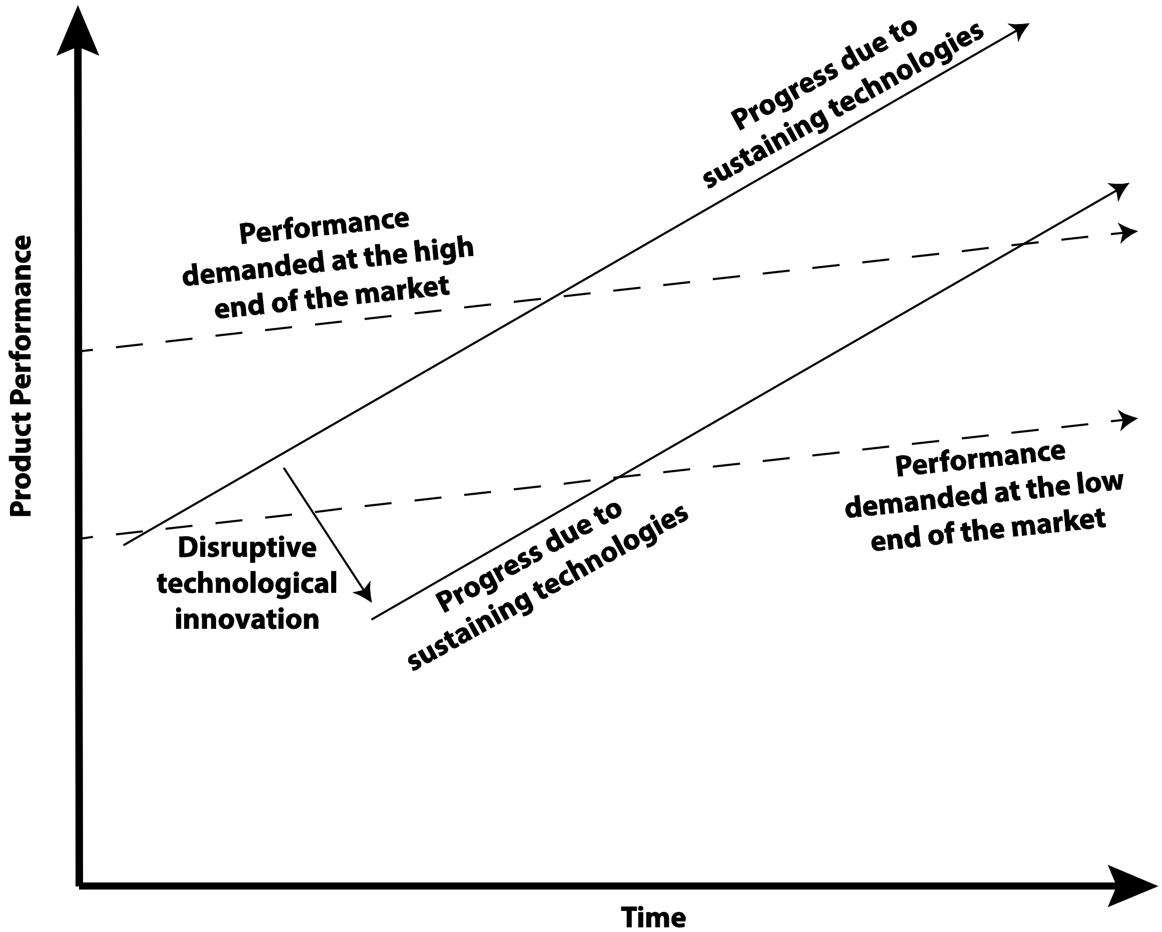


Figure 3: Disruptive Versus Sustaining Technological Change (Derived from, Christensen, 1997, p. xvi)

Christensen lists several other principles that come into play, resulting in great firms' susceptibility to being *disrupted*. Companies are dependent on current customers and investors for resources. So they can't justify investment in disruptive technologies, which will compete on performance metrics unimportant to current customers, and which are currently unknown to the company. The larger a company becomes, the larger a market each new product innovation requires to make the same percentage impact on the company's results. Large companies need to show ongoing growth, so they can't waste valuable resources on small markets. Good, established companies excel at analyzing their customers' needs and their markets, but markets that don't exist yet can't be analyzed. Good, established companies have established values and processes that work for the market they compete in. These values and processes tend to be inflexible and can be disabilities in new markets.

2.2.3.1 Criticism

One criticism of *The Innovator's Dilemma* was that it offered no constructive suggestions on how current market leaders could avoid being disrupted or lead the inevitable disruption. *The Innovator's Solution* (Christensen & Raynor, 2003) and *The Innovator's DNA* (Dyer, Gregersen, & Christensen, 2011) addressed these shortcomings.

Danneels (2004) notes a lack of constructive criticism of Christensen's theory of disruptive innovation. However, Danneels offers little criticism himself. Instead, he proposes linkages "to a wide range of related literature streams" and offers suggestions for future research. One criticism he does offer is that Christensen does not "establish a clear-cut criteria to determine whether or not a given technology is considered a 'disruptive technology'" (p. 247). Otherwise, Danneels is a clear supporter of Christensen's work, defending him from the criticisms of Cohen (2000). Cohan accuses Christensen of selectively choosing examples to support his theory, that he selected technologies that succeeded and ignored many potentially disruptive technologies that failed. The criticism is that companies have no way of knowing ahead of time which technologies will be the successfully disruptive ones. While this is true, Christensen's model provides some hints as to where and when companies should be looking for disruptive technologies. Danneels merely suggests that future research should focus on developing tools to predict disruptive technologies but offers little in the way of how this should be done. He does suggest the use of two techniques, including the Delphi method, to predict disruptive technologies, but I tend to side with Christensen here when he says, in his earlier work (Christensen, 1992), that you can't predict what technological developments will be disruptive. It's like trying to develop a viral video. You can try. You can do all the things that are purported to be the 'right' things. In the end, what goes viral cannot be consistently and accurately predicted. In a similar vein, musicians, and their producers, will admit that they can't predict which of their songs will be a hit (Suhr, 2015). This is to be expected in all areas that operate according to the principles of complexity (Stacey, 1996); as technology management specifically – and business in general – does… as creativity does.

Cohen (2000) also questions whether setting up a new, separate organization is always the best approach for handling disruptive technologies. He presents two examples that he claims support his case: Hewlett Packard with inkjet printers, and Schwab with online stock trading. Danneels (2004) discounts both of these examples, showing that in both cases the innovation was incubated in a new, separate division.

In the popular press, Thompson (Thompson, 2015) argues that Apple has proven to be Christensen's "bugaboo." Apple has disrupted the mp3 player market and the smartphone market. It has grown to be the world's largest corporation, yet it continues to disrupt and avoid disruption. Lepore (Lepore, 2015) discounts Christensen's research and conclusions because it "is based on hand-picked case studies." Yet this is the nature of the case study method. Particularly when using case studies to develop theory. Those who feel his theories are wrong could go off and do their own large-N studies to attempt to disprove the theory. Christensen adequately explained his rationale for choosing the industries he studied. Some of Lepore's other criticisms seem trivial to the point of nit-picking – assuming

Christensen is proposing a theory, rather than suggesting an established fact with universal applicability.

In *The Innovator's Dilemma*, Christensen provides a useful framework, or perspective, for viewing, analyzing, and interpreting a set of technologies and their markets. While this framework's predictive ability is limited, it does provide a rational way of interpreting a competitive landscape which should improve a company's chances of disrupting a market or avoiding disruption. In Christensen and Raynor's words: "Disruption is a theory, a conceptual model of cause and effect that makes it possible to better predict the outcomes of competitive battles in different circumstances" (2003, p. 55). However, if all companies applied this framework equally well, I suspect the advantage would go to the small startup if for no other reason than the "asymmetry of motivation" (Christensen & Raynor, 2003, p.55).

2.2.4 The Innovator's DNA

In *The Innovator's Solution*, Christensen and Raynor (Christensen & Raynor, 2003) offer companies guidance to avoid being disrupted and to introduce disruptive technologies. However, as Kastelle (2012) points out, Kodak saw the disruption of digital photography coming decades before their demise. In 1975 Kodak had developed one of the first digital cameras, and an internal report predicted, in 1979, that the market would completely shift to digital by 2010. Yet Kodak failed to make the changes necessary to survive in their disrupted market.

The competitive landscape is littered with the corporate carcasses of companies that couldn't survive disruption, even when they saw it coming. Blockbuster, Blackberry, Nortel, just to name a few.

In *The Innovator's DNA,* Dyer, Gregersen & Christensen (2011) outline what they feel are the skills and activities required for individuals and corporations to develop disruptive innovations and avoid disruption. Their research led them to the conclusion that successful, highly innovative people excelled at association. "Their minds excel at linking together ideas that aren't obviously related to produce original ideas (we call this cognitive skill 'associational thinking' or 'associating'" (p.3). But their research also indicated the ability to come up with innovative ideas was not just a matter of how innovators thought – it was related to behaviour. In fact, it seems that four behaviours tend to improve a person's associational thinking ability. These behaviours are: questioning, observing, networking, and experimenting.

Dyer and his colleagues went further and asked why innovators tend to question, observe, network and experiment more than non-innovators. Their conclusion was that innovators want to challenge and change the status quo, and they are willing to take a risk to make change happen.

Dyer, Gregersen & Christensen have drawn heavily on creativity literature. Associational thinking is a core element in their model. One cognitive theory of creativity "argues that creative insights can result from associative processes" (Kozbelt et al., 2010, p.32). In this theory, it is remote associations, or 'remote associates,' that tend to be novel. Dyer, Gregersen & Christensen also refer to Alex Osborn's creative problem-solving techniques and Bob Eberle's SCAMPER acronym. SCAMPER stands for: substitute, combine, adapt, magnify, minimize, modify, put to other uses, eliminate, reverse, and rearrange. It is a brainstorming technique used to generate new ideas and to come up with improvements to existing ideas.

Finally, Dyer, Gregersen & Christensen note that innovators tend to have T-shaped expertise. That is, they have deep knowledge in at least one area and some expertise in a wide variety of areas. This is referred to as T-shaped knowledge in the field of creativity research and is thought to be a factor that contributes to remote associations.

While *The Innovator's DNA* is consistent with creativity research, and draws heavily on it, it tends to propagate the lone genius myth. Researchers such as Keith Sawyer (2008) suggest that collaboration is the key to what he terms breakthrough creativity. It seems intuitively obvious that the associational thinking we can achieve as individuals could be made to look insignificant when compared to the associational thinking that could be achieved in groups. Perhaps what is really going on with the lone innovators Dyer, Gregersen & Christensen studied is that they help create an environment where group-associational thinking can flourish.

2.2.5 Big-Bang Disruption

Downes and Nunes (Downes & Nunes, 2014) propose that the bell curve and the resultant S-curve of diffusion/adoption are dead. They claim that because of changes in technology the curve now consists only of two segments – trial users, and everybody else – and that the curve has been severely squashed. In their model, the adoption curve goes almost straight up after reaching the 'everybody else' segment. It also comes back down almost as quickly.

Their model suggests that classic rules of business don't apply to these disruptors. Convention would suggest focusing on one strategy: low-cost leadership, product innovation leadership, or customer intimacy leadership. Their so-called "big-bang wisdom" is to focus on all three at once. Convention – Rogers and Moore in this case – would suggest marketing to one segment at a time. Downes and Nunes state that today's disruptive companies need to market to all segments right away. They need to be ready to scale up quickly, and to exit just as quickly. When it comes to innovation, they note that conventional wisdom – Christensen's in this case – is to innovate in lower-cost, feature-poor technologies that will meet the needs of a new, or underserved customer. Their big-bang solution is rapid, low-cost experiments on popular platforms.

While there is some value to their model, it seems to have limited applicability. While it seems plausible that many crowd-funded startup products have a diffusion curve that goes almost straight up – should the crowd-funding go viral – many have a more traditional adoption curve. One example the authors refer to is the NeoLucida. According to the product website (NeoLucida, 2015), it "is a drawing aid that allows you to trace what you see. It's a modern reinterpretation of the camera lucida, an indispensable drawing tool popular in the days before photography." This company has not exited rapidly. They appear to be working through the early majority, with plans to continue selling products to the late majority and, eventually, the laggards.

What appears to be going on in crowd-funded cases like NeoLucida is that all the early adopters get squeezed into a brief spike. The product developers (change agents in Rogers' terminology) are then left with a choice at the end of their crowd-funding campaign. Fulfil all the orders, then take the money and run, or attempt to cross a new and different type of chasm. New because this is a chasm that has been created by the relatively new phenomenon of crowd-funding. Different for several reasons. First, most crowd-funded products are consumer products. Moore claims that *Crossing the Chasm* only applied to business-to-business products. Secondly, this chasm could be much wider, since the whole early adopter segment is squeezed to the left, and the company is then left focusing on fulfilling orders, often to the detriment of marketing to the early majority.

Another example the authors use to make their point is Twitter. Twitter was founded in 2006. It saw relatively slow adoption until 2010, when it seems to have hit the tipping point. Growth continued to accelerate until the first quarter of 2012. Now Twitter seems to be tapering off and just picking up the laggards (see Figure 4). Twitter's growth seems to follow a classic technology adoption lifecycle.

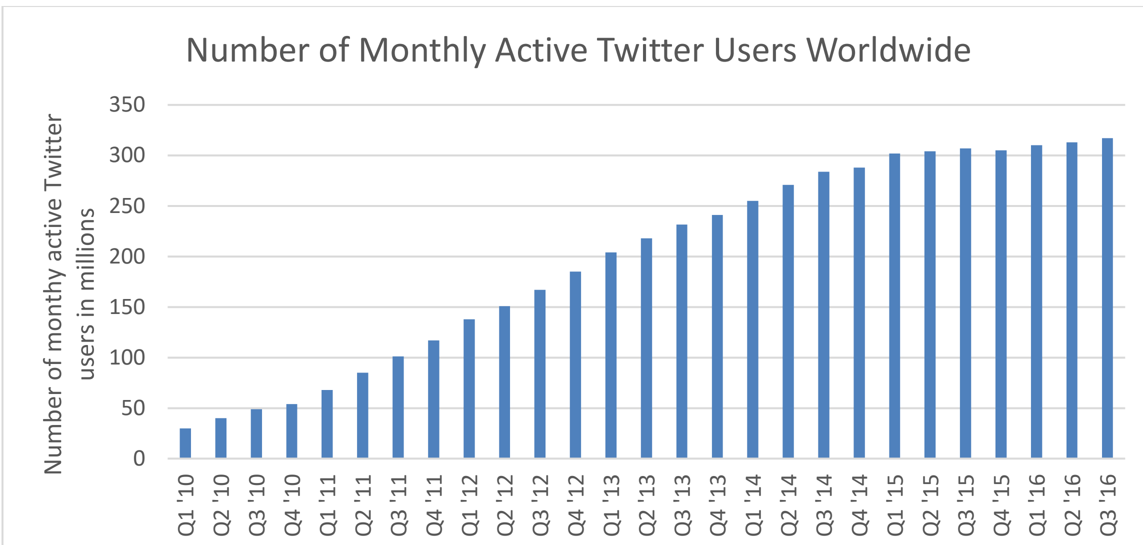


Figure 4: Twitter Adoption (Data source: "Twitter: number of active users 2010-2016," 2016)

One of the better examples used to drive home the point of *Big-Bang Disruption* is Google maps enabling free navigation, quickly disrupting companies such as Garmin Inc. Downes & Nunes (2013) summarize the situation as follows:

> Google Maps Navigation competes with stand-alone GPS devices on all three value disciplines: It is clearly the cost leader. It is constantly being updated and rereleased, making it the leading innovator as well. And by offering seamless integration with mobile phone contact lists, the web, e-mail, and apps such as Yelp, it likewise wins

on the dimension of customer intimacy. No surprise, then, that after years of steady growth, the GPS device industry is in a tailspin. Garmin lost 70% of its market capitalization in the two years after navigation apps were introduced; TomTom nearly 85%. (p. 51)

But this can be interpreted in a very different way. Google maps had its start as a desktop application developed by Where 2 Technologies. Google acquired the company in 2004 and turned the product into a web-based application in 2005. Google maps for mobile was not released until 2013 – eight years later. During those eight years, smartphones were making the type of progress that can be expected in a world where computing power doubles every 18 months. Given Google's typical business model, and the fact that Google Maps was always freely available on the web, the transition to a mobile platform – one that Google themselves created and made freely available (Android) – was inevitable. If Garmin did not see this coming, they would deserve to be decimated. But they weren't. While their stock price, and therefore their market capitalization, may have taken a big hit, their revenues did not (see Table 1).

Fiscal Year (Jan - Dec)	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005
Revenues (US$ - Billions)	2.82	2.87	2.63	2.72	2.76	2.69	2.95	3.49	3.18	1.77	1.03
Gross Profit (US$ - Billions)	1.54	1.6	1.41	1.44	1.34	1.35	1.44	1.55	1.46	0.88	0.54

Table 1: Garmin Revenue (Data Source: ("Garmin Income Statement," 2016)

Garmin has many product models that go far beyond what Google Maps' Android app provides. No doubt their revenues would have grown faster if they did not have to contend with this competitive threat, but this was not a threat that no one could see coming. This was also not a threat that jumped from 0% to 100% adoption almost overnight, as implied by Downes & Nunes.

While crowd-funding and viral marketing may cause some new kinks in the innovation adoption lifecycle, it was never envisioned to be a nice smooth curve in practice. Just as the adopter type doesn't suddenly change when a well-defined line is crossed, we also can't expect a perfectly smooth S-curve that is identical from one instance to the next. The adoption S-curve is an idealized model that presents a useful way to view a process. The fact that individual instances are going to vary – sometimes considerably – from the idealized model, should be obvious to the reader. Should it not be obvious, perhaps the value in *Big-Bang Disruption* is in making it clearer that each product's diffusion curve will be unique. Some companies may benefit from the warnings to watch out for the unexpected, sudden disruption, but I don't find *Big-Bang Disruption* adds a lot of value beyond what Rogers, Moore, and Christensen have already written.

2.2.6 Overview of other theories of innovation.

The preceding sections covered a small sample of the many theories of innovation. They were selected largely to illustrate the prevalence of the assumption that adoption rates follow a normal distribution. However, this assumption does not always hold. This subject will be discussed further in one of the articles.

The rest of this section will briefly cover some of the other theories of innovation.

2.2.6.1 Creative Destruction

Joseph Schumpeter was an economist and political scientist whose work spanned the first half of the twentieth century. However, interest in his work saw a resurgence after his death in 1950, as his predictions about entrepreneurship and capitalism began to appear more and more prescient.

Schumpeter argued that the success of capitalism would be its own undoing. He predicted that capitalism's support of the entrepreneur would lead to corporatism. Successful corporations would become monopolistic and would greatly influence public policy. Schumpeter warns that this will lead to rising unemployment, a lack of fulfilling work, unrest, protests, and intellectual criticism. He further predicts this will lead to the election of more social democratic parties.

Schumpeter is perhaps best known for popularizing the term *creative destruction*. In *Capitalism, Socialism and Democracy*, Schumpeter (1950) describes creative destructions as a:

> process of industrial mutation […] that incessantly revolutionizes the economic structure *from within*, incessantly destroying the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism. It is what capitalism consists in and what every capitalist concern has got to live in. (p. 83)

In a footnote to this description, Schumpeter clarifies his meaning of incessant. He viewed the process as a whole as incessant, but saw the revolutions occurring within the overall process as "discrete rushes which are separated from each other by spans of comparative quiet." Schumpeter viewed changes occurring within a capitalist economy from an evolutionary perspective, with entrepreneurs as the driving force of evolutionary change. Entrepreneurs, he argued, drive this change by capitalizing on innovation.

Schumpeter's description of "discrete change" and "spans of comparative quiet" foreshadowed the punctuated equilibrium theory of evolution that became commonly accepted years after Schumpeter's death. Punctuated equilibrium theory matches the fossil record better than its predecessor, phyletic gradualism. Phyletic gradualism assumes evolution occurs at a relatively constant, uniform rate. Punctuated equilibrium, on the other hand, predicts long periods of relative stasis, punctuated by sudden, rapid evolutionary change (Benton & Harper, 2009; Gould & Eldredge, 1977). Sneppen, Bak, Flyvbjerg, & Jensen (1995), have explained and mathematically modelled punctuated equilibrium macro-evolution in terms of self-organized criticality. Self-organized criticality arose from the field of complexity science and is seen as a property of dynamical systems[24], which results in periods of relative stasis followed by brief periods of rapid change. When viewed over the long term, these periods of change result in a large number of small changes and a smaller and smaller number of larger and larger changes. Self-organized criticality will be discussed further in the section on complexity.

Christensen supported Schumpeter's analysis that previous markets are destroyed by innovation. Christensen saw the mechanism behind creative destruction as disruption. However, there is one significant point of contention between the two theories. Schumpeter thought large companies had an innovation advantage due to their monopolistic power. Christensen's theory suggests that innovation, and disruption, comes from smaller firms. As large firms continue to acquire smaller startups to acquire their talent, technology and ideas, it seems the "innovation" strategy of some large firms is driven by mergers and acquisitions (Reuters, 2018). In a fairly recent review, Baker (2007) has concluded that the enforcement of anti-trust laws is good for innovation.

2.2.6.2 Slow Starts

The productivity paradox refers to the observation that the long-expected productivity gains from the increasing use of computers have not materialized. There has

[24] A dynamical system is simply a system that changes over time.

been a “clash of expectations of and statistics” (Brynjolfsson, 1993). In a more general sense, the productivity paradox refers to any instance when a new technology is not delivering the expected increases in productivity.

David (1990), argues that this is typical when any type of general purpose engine diffuses throughout a socio-economic system. For his purposes, he describes a general-purpose engine as “key functional components embodied in hardware that can be applied as elements or modular units of the engineering designs developed for a wide variety of specific operations or processes” (p. 355). In addition to the computer, he cites the steam engine and the dynamo as examples that did not produce the productivity gains expected; at least, not in the timeframe expected.

David suggests that there are several issues that lead to this paradox. One of the larger issues is that the transition to a new ‘techno-economic regime’ requires a considerable amount of time for supporting infrastructure to adjust. Also, methods, procedures, and modes of thinking take time to adjust while industries slowly determine how to fully capitalize on the new technology. There is also the unprofitability of replacing still-serviceable technology from the old regime which slows down investment in the new technology.

David also discusses a different consideration that contributes to the apparent productivity paradox. That of what is measured and how. He notes that the introduction of a new, general-purpose engine results in quality changes that are not captured by existing measurement systems and the introduction of new “goods and services that previously were not being recorded in the national income accounts” (p. 358). That is, much like Christensen’s disruption, new general-purpose technologies frequently support new products and services that compete on new attributes that weren’t being considered previously.

2.2.6.3 Extended Life Cycles

While the productivity paradox deals with the slower than expected diffusion of new technologies, the other end of the innovation lifecycle has also been shown to frequently experience a longer than expected time frame. That is, technologies that have been predicted to be replaced by new technology sometimes find ways of remaining competitive for many years. Examples include the carburetor, optical photolithographic alignment technology, CISC processor architecture, and manual typesetting (Henderson, 1995; Snow, 2004, 2008).

Snow (2004; 2008) describes this phenomenon as a technology's 'last gasp.' He notes that the conventional explanation for the phenomenon has been the result of the extra effort put in by competitors who produce the threatened technology, once the threat to survival becomes apparent. That is, the theory has been that they try harder (Rosenberg, 1976). While, as Snow points out, this explanation may have intuitive appeal, Snow's research suggests two other reasons for a technology's sudden performance leap late in its life cycle.

One reason is that the threatened technology is first forced out of markets where it is least competitive. The old technology's market space is slowly reduced to the segments where it is most competitive. As its market share is weened to areas where the old technology's relative performance is best, its average performance improves.

The second reason Snow found was that the old technology often borrows some aspects of the new technology. He provides the example of carburetor manufacturers significantly increasing fuel economy, after the introduction of the competing electronic fuel injection (EFI) technology, by adopting some of the technology that went along with the new technology. That is, carburetors began to make use of the electronic fuel control systems, developed to enable the use of EFI in cars, to better manage fuel usage and increase economy.

In another perspective of the extended life cycle, Henderson (1995) looks at the "unexpectedly long old age of optical lithography." He points out how the predicted limits of optical photolithography have been exceeded over and over again, throwing into question the belief of "several authors have… that one can predict the limits of a technology from a knowledge of the laws of physics" (p. 631). For instance, Henderson points out that industry experts predicted (around 1995, when he wrote the paper) that the wavelength of visible light would limit the performance of optical aligners to about 20 μm.

With the benefit of hindsight, we can now see that Henderson was right. More than 20 years after Henderson wrote about the unexpectedly long old age of optical lithography, immersion lithography now goes down to 32 nm ad the next generation lithography is expected to go down to 22-16 nm using extreme ultraviolet, X-ray, electron beam or ion beam technology.

Perceived limitations to a technology are always being broken. And if the new path to improved performance was obvious – easily predictable – it wouldn't be considered an innovation. For example, Moore's law[25] has lasted longer than many expected due to innovations such as multi-threading, multiple cores, improvements in optical lithography, and 3D cores (which are still experimental but could be the next big thing to extend Moore's law). Moore's law has lasted a long time due to innovations – as did optical lithography and disk drive storage.

How these innovations are seen is often a matter of perspective. What is an innovation within the dominant technology to some, may be a jump to a new dominant

---

[25] that the number of transistors that can be put on an integrated circuit doubles approximately every 18 months

technology to others. For example, from the user's perspective, the evolution from hard disk drives to solid state drives is incremental – an innovation within the dominant technology. From the producer's perspective the evolution from hard disk drives to solid state drives is discontinuous (which may also be referred to as radical, disruptive, a jump to a new dominant technology).

The point being that the S-curve of the innovation lifecycle is made up of multiple, interacting innovation life cycles, which is likely best viewed from the perspective of the end-user. That is, there are so many factors affecting the innovation lifecycle – the innovation lifecycle of components, and of related technologies, customer preferences, supporting infrastructure – that the interrelationships between all of these factors results in a complex system.

2.2.6.4 Nobody Knows Anything

In yet another view of the diffusion of innovation, Walls (2005) demonstrates that a review of box office receipts supports Goldman's (1983) dictum that "nobody knows anything." Goldman was referring to the fact that all of the experience, market research, focus groups, and analysis of Hollywood studios, no one has any idea how well a movie will do before it is released.

De Vany's (2006) research shows that box office revenues follow a power law[26] distribution rather than a Gaussian (normal) distribution. Large-scale events are more likely

[26] De Vany actually refers to the distribution as "the stable Paretian distribution," but since the Paretian distribution is a particular power law distribution, I will refer to the more general term – power law distribution – in order to maintain consistency with other parts of this dissertation.

in a system with a power law distribution than in with a normal distribution. These large events, far out on the tails of the distribution, dominate any sample statistics. Other characteristics include infinite variance and, as De Vany notes "for some variables, even the mean does not exist." Therefore, movie box office receipts have no natural scale, and the words *typical*, or *average,* do not apply – they lose their meaning in a power law system.

De Vany points out that studios have adopted business practices that are "rational adaptations" to the uncertainty that is characteristic of systems best modelled with a power law. This uncertainty, and the power law distribution, are also characteristics of complex systems – the topic of the next section.

2.2.7 Links to Complex Adaptive Systems

Everett Rogers, et al. described several similarities between the diffusion of innovations model and complex adaptive systems. They point out that both deal with change and the method by which a population of agents transition, or evolve, to higher fitness peaks. Both describe a method of evolution that is dependent on heterogeneous networks of agents. In both cases, the network consists of highly interconnected local groups, with sparser interconnections between those local groupings (Everett M Rogers et al., 2005). In other words, Rogers and his colleagues are saying that both the diffusion of innovations model and complex adaptive systems are dependent on small-world networks.

As discussed in the previous section, Walls' (2005) and De Vany's (2006) movie industry researched illustrates two characteristics of complex adaptive systems – uncertainty and power-law distributions. The uncertainty is a result of the *sensitive dependence on initial conditions* characteristic of complex adaptive systems. This, and other characteristics of complex adaptive systems, will be further explored in the next section.

In *The Nature of Technology: What It Is and How It Evolves*, Brian Arthur (2009) describes, in detail, a complex-adaptive-systems-based theory of the evolution of technology. While he does not directly discuss the diffusion of innovations, his theory implies that the diffusion of all new technologies (innovations) is the result of a complex adaptive system. See section 2.3.6 for more on Arthur's theory.

The link between creativity and innovation should be clear – innovation is the implementation of creative ideas. Given the clear linkage between creativity and innovation, and between innovation and complexity, the reader may begin to glimpse the connection between creativity and complexity. If not, that connection should become clear in the following sections.

2.3 Complexity

This section begins with a discussion about defining the term *complexity*, within the context of complexity science, and continues with an overview of five different views of complex systems. These views are presented by reviewing the work of five complexity science researchers who approach the topic from very different perspectives. The section concludes with a discussion of some of the most salient features of complex systems common to most perspectives.

2.3.1 Defining Complexity

One hundred ants on their own will not survive, but put one hundred thousand together and they exhibit what many have called collective intelligence. Melanie Mitchell (Mitchell, 2009) describes how this, and other mysteries, form part of what has come to be known as complexity science.

> The mysteries of army ants are a microcosm for the mysteries of many natural and social systems that we think of as 'complex.' No one knows exactly how any community of social organisms – ants, termites, humans – come together to collectively build the elaborate structures that increase the survival probability of the community as a whole. Similarly mysterious is how the intricate machinery of the immune system fights disease; how a group of cells organizes itself to be an eye or a brain; how independent members of an economy, each working chiefly for its own gain, produce complex but structured global markets; or, most mysteriously, how the phenomena we call 'intelligence' and 'consciousness' emerge from nonintelligent, nonconscious material substrates. (p. 4)

Much like ant colonies, neurons in our brains operate by firing when they receive sufficient levels of inputs from other neurons. Taken together, the trillions of neurons in each of our brains give rise to the emergence of thoughts, feelings and consciousness. The jump from the relatively simple operation of a lone ant or neuron to the complex behaviour of ant colonies or our brains is not well understood, but it is at the heart of complexity science.

As with most paradigms early in their evolution, definitions abound without any one definition of complexity yet garnering broad support. However, in order to discuss complexity, it is important to understand the difference between *simple*, *complicated* and *complex*. This is best done by illustrating with examples.

Baking a cake by following a recipe is simple. No particular expertise is required, you can be quite certain of the results from one time to the next, and everything required for success can be captured in the recipe. Building a rocket with a Mars landing vehicle is complicated. It takes a high degree of expertise in many different fields, coordination of efforts, and formulae that can be applied with some assurance. There is a reasonable degree of certainty of the outcome, but it is not assured. Building one successful rocket increases the odds of a subsequent attempt being successful (for that matter, so does building an unsuccessful one, since what is learned will be applied to the second). Rockets are similar to each other in critical ways. Raising children is complex. One success may not have any bearing on the success of a subsequent attempt. Formulae have limited application, expertise can help, but is not sufficient. Each child is unique and there will always be uncertainty in the outcome (Glouberman & Zimmerman, 2002, p. 2).

In *Complexity: 5 Question*s (Gershenson, 2008), twenty-four researchers were asked five questions about complexity, including "how would you define complexity?" Of these twenty-four, only one directly answered the question, saying that "Complexity is that property of a model which makes it difficult to formulate its overall behaviour in a given language/framework, even when given reasonably complete information about its atomic components and their interrelations" (Edmonds, 2008, p.46). Others, instead, gave examples, gave a definition for complex systems (rather than complexity), or discussed the futility of defining complexity. Anderson, for example, said "I think it's a mistake to try to define complexity" (2008, p. 6), while Arthur wrote "I do not think of complexity as having a definition" (2008, p. 10), and Heylighen responded to the question with "Dozens if not hundreds of authors have proposed definitions, some vague and qualitative, some formal and quantitative, but none of them really satisfactory. The formal ones tend to be much too specific, being applicable only to binary strings or to genomes, but not to complex systems in general" (2008, p. 69). Mitchell's (2008) answer seemed to sum up the prevailing sentiment well:

> I don't think there is a single good definition, just as there is no single good definition of 'self-organization' or 'emergence'. People use words like this in different ways in different contexts. There is a well-known paper from 2001 by Seth Lloyd describing about 40 different definitions people had proposed, and there have been lots more since. None are really satisfactory, in my opinion. (p. 96)

While most complexity researchers shied away from defining the term *complexity*, they showed no such reluctance when it came to the term *complex system*. Newman defined a complex system as "a system composed of many components or 'agents', which interact with one another so that the system as a whole is more than just the sum of its parts. We say the system shows 'emergent behaviours', collective responses of all the parts that make it up" (2008, p. 102). Solé (2008) defined a complex system as a

> set of elements interacting in such a way that higher-order, system properties emerge. These properties cannot be reduced to the properties displayed by individual parts and thus some kind of 'irreducible order' is at work. I would add to this tentative definition that complexity is strongly tied to an unbreakable dialog between system and parts: the global pattern is generated by individuals, who also receive feedback from the system. (p. 124)

Elsewhere, complexity researchers explain that the *science of complexity* is the study of nonlinear feedback networks, particularly complex adaptive networks, or systems. In *Complexity: A Guided Tour*, Mitchell (2009) defines a complex adaptive system as "a system in which large networks of components with no central control and simple rules of operation give rise to complex collective behaviour, sophisticated information processing, and adaptation via learning or evolution" (p. 13). Mitchell also proposes an alternative definition based on the behaviour of such systems: "a system which exhibits nontrivial emergent and self-organizing behaviours" (p.13). In defining complex systems, Holland (2014) highlights the difference between complex physical systems and complex adaptive systems. He describes complex physical systems as "arrays of elements, in which interactions typically depend only on effects propagated from nearest neighbors" (p. 6), while complex adaptive systems consist of elements – usually called agents – that learn or adapt as they interact with other agents and their environment. The range of interactions – breadth and depth – and adaptation are the key differentiators. However, as with so many things that are discussed as though they are dichotomies, or binaries, these systems exist on a continuum. Systems on one end of the continuum are clearly complex physical systems. Systems on the other end of the continuum are clearly complex adaptive systems. There is not a clear dividing line between the two.

The rest of this section provides an overview of the way five authors, with five different perspectives, view complexity science.

2.3.2 How Nature Works: The Science of Self-Organized Criticality [27]

"*An unlikely event is likely to happen because there are so many unlikely events that could happen*" (Bak, 1996).

Bak (1996) suggests we think of complexity as variability. He points out that the reductionist methods of physics and other sciences – predictions that are supported by

[27] The content for much of this section was derived from Bak's' (1996) *How Nature Works*. Page references in this section are to this book, unless otherwise noted.

reproducible experiments – are impossible in many areas of scientific interest. He argues that in the social sciences, contingencies are pervasive, with the result that detailed long-term prediction becomes impossible. Karl Popper has argued that prediction is the best means of distinguishing science from pseudo-science. Fortunately, we can predict that a complex system will exhibit certain patterns. Some of those predicted patterns are revealed in the following discussion.

Per Bak's (1996) theory of *self-organized criticality* proposes that many systems in nature evolve to a critical state, which is way out of balance. In this critical state, minor disturbances result in events – called avalanches in Bak's terminology – of all sizes.

Bak explains self-organized criticality with a sand pile. Start by dropping a grain of sand on a table, wait for it to come to rest, drop another grain of sand from the same location and wait for it to come to rest. If you continue repeating this long enough, eventually a sandpile will form and it will reach a critical state – a state where the next grain of sand produces a disturbance in the sandpile when it lands, resulting in an avalanche. This avalanche may be large or small. Even if each grain of sand is identical – to the limits of our ability to measure such things – the size of the resultant avalanche depends on the complex interrelationships between the thousands of grains of sand already in the pile. They are poised at a critical state where the next grain of sand to fall will hit a grain of sand in the sandpile in such a way that it is knocked from its perch. Often, this one grain of sand will tumble down the side of the sandpile and come to rest at some point without disturbing other grains sufficiently to knock them from their resting locations. However, sometimes this one grain of sand that is dropped on the unsuspecting sandpile will knock more than one grain of sand from their resting points, sending them tumbling down the side of the sandpile, knocking other grains loose on their way. These other grains of sand may then disturb other grains of sand sufficiently to knock them loose and in short order what can be referred to as a catastrophic avalanche, where a large fraction of the grains of sand have been disturbed, has taken place.

Years of studying sandpiles and other phenomena have shown that the distribution of these avalanches follows “well-defined statistical properties” (p. 58). That is, there are many small avalanches and fewer large avalanches. The distribution of avalanche size follows what is called an inverse power law, which can be represented as $f(x) = \frac{1}{Kx^n}$

The inverse power law describes the relationship between two quantities when a change in one quantity gives rise to a proportional, but nonlinear, inverse change in another quantity. For the sandpile example, the proportional inverse relationship exists between the frequency and the size. That is, as the size of avalanches goes up, the frequency goes down. See Figure 5 for an example of what this can look like when plotted.

Other examples of natural systems that exhibit inverse power law relationships include earthquakes, rainfall, temperature and other weather-related events, the size of islands and of lakes, the height of mountains, and the erosion of river beds.[28] In all cases listed, the size or intensity varies inversely with frequency. Examples of inverse power law relationships resulting from human societies include the size of cities, the size of crowd-funding campaigns, stock markets (including percentage up or down each day, stock prices, change in price, volume traded each day), distribution of income, and the size of businesses. Andriani and McKelvey (2007) list forty examples of power law phenomenon from natural sciences and forty examples from social science. There are likely many more.

---

[28] Not all of these examples are without controversy. In particular, the claim that weather related data follow an inverse power law is not, as yet, widely accepted.

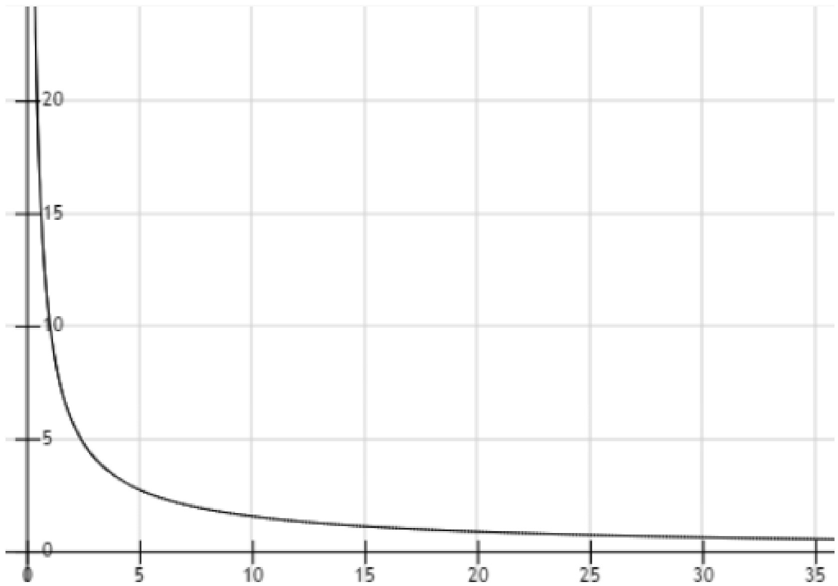


Figure 5: Example of an Inverse Power Law Plot

If, for the example given in Figure 5: Example of an Inverse Power Law Plot, the log of the units for each axis is used and the log of the results is plotted, it will come out as a straight line. This provides a simple test to see if a system behaves according to the inverse power law. It is also related to one of the interesting features of the of inverse power laws: scalability – also referred to as scale independence, self-similarity, scale invariance, or scale-free. Bak explains scale invariance as follows:

> The scale invariance can be seen from the simple fact that the straight line looks the same everywhere. There are no features at some scale that makes that particular scale stand out. There are no kinks or bumps anywhere. Of course, this must eventually break down at small and large scales. There are no fjords larger than Norway. And no fjords smaller than a molecule of water. (p. 27)

While Bak is talking about the straight line in a log-log power law plot, scale invariance can also be seen with the normal inverse power law plot by zooming in or out.

The plot will look the same at various magnifications. Bar-Yam (2011) explains scale independence this way:

> Power laws are very important because they reveal an underlying regularity in the properties of systems. Often highly complex systems have properties where the changes between phenomena at different scales is independent of which particular scales we are looking at. The picture we take at one scale is therefore similar in some way to the picture we take at another scale. This self-similar property underlies power law relationships.

Other interesting features of inverse power laws include the lack of a well-defined mean, near infinite variance, and interdependence. The fat tail of the inverse power law means we can expect more extreme events (sometimes referred to as catastrophes) in these systems than in systems that can be described by the Gaussian distribution. These extreme events, while small in frequency, are large in magnitude. This large magnitude number tends to overpower the high frequency of small numbers. Therefore, if we were to collect a large number of readings from a system that follows the inverse power law, and compute an average, at any time the very next data point collected could significantly affect the calculated average. With a Gaussian distribution, the more data collected, the more we can expect the sample average to converge on the population average. A similar argument holds for the calculation of the variance of an inverse power law dataset. The extreme values send the calculated variance to extreme values – tending toward infinite variance.

These extremes are a result of the interdependence of *agents*. In the case of sandpiles, agents are the individual grains of sand. In the case of most social science examples, agents are individual human beings. In the case of sandpiles, one agent is in contact with many neighbouring agents, resting on some, supporting others, and merely touching still others. Of course, those neighbouring agents are resting on, supporting, or touching many others. In effect, every grain of sand in the sandpile is connected to every other grain through a network of neighbouring grains. When just one grain is disturbed, it may do nothing but vibrate a bit and then settle back into place. Or, it may set off a chain reaction resulting in an avalanche the likes of which this sandpile-world has never seen before.

Kauffman (1995) explains that in self-organized systems that have evolved to the point of criticality, there is statistical order in the distribution of avalanche sizes, but there is no way to predict the result of each individual case. Kauffman theorizes that biological evolution exhibits self-organized criticality and that it is the "nature of coevolution to attain this edge of chaos, a web of compromises where each species prospers as well as possible but where none can be sure if its best next step will set off a trickle or a landslide" (p. 29).

Bak discusses how extinction events have been shown to follow the inverse power law, not because of the varying size of meteors hitting the earth, or other catastrophes, but because of the interconnected food web. The effect of one species going extinct – perhaps from a natural disaster – can ripple throughout the food web and cause an avalanche of extinctions. This avalanche may be large or small, but the chilling conclusion is that survival of the fittest may not be all that it has been held up to be. Survival may have more to do with luck than fitness. Bak elaborates by saying:

> Large catastrophic events occur as a consequence of the same dynamics that produces small ordinary everyday events. This observation runs counter to the usual way of thinking about large events, which, as we have seen, looks for specific reasons (for instance, a falling meteorite causing the extinction of dinosaurs) to explain large cataclysmic events. Even though there are many more small events than large ones,

most of the changes of the system are associated with the large, catastrophic events. (p. 32)

Besides the occurrence of catastrophic events predicted in systems which have evolved to self-organized criticality, Bak explains that they also exhibit fractals, Zipf's law, and 1/f noise. He notes that these phenomenon "are so similar, in that they can all be expressed as straight lines on a double logarithmic plot, that they make us wonder if they are all manifestations of a single principle" (p. 31). He goes on, unsurprisingly, to argue that that principle is self-organized criticality.

In many ways, this seems to be a simplistic statement since they do all seem to be related. For instance, a fractal is defined as "any of various extremely irregular curves or shapes for which any suitably chosen part is similar in shape to a given larger or smaller part when magnified or reduced to the same size" ("Fractal," 2017). If 'extremely irregular' is dropped from this definition, the result is the definition of self-similarity seen in the power law curve. Furthermore, Zipf's law is just a specific case of the inverse power law. Zipf's law states that for any given text, or set of texts, the frequency of occurrence of a word is inversely proportional to its rank in a table of word-use frequencies. In the simplest case, the most frequently used word will be used twice as often as the second most frequently used word, three times as often as the third most frequently used word, etcetera (Adamic, n.d.). Finally, 1/f noise, also called pink noise, is another specific case of the inverse power law. It occurs when the energy per frequency interval is inversely proportional to the frequency of the signal. So, it's not surprising that we see a straight line in each case when plotted on a log-log plot.

The demonstration of a power-law relation in data may point to specific underlying probability mechanisms and a deep connection with other, seemingly unrelated systems

(Simon, 1955). Bak's theory is that self-organized criticality is that underlying mechanism. He argues that the process of self-organized criticality takes place over a long period of time; that it is a long process of evolution.

2.3.3 At Home in the Universe: The Search for the Laws of Self-Organization and Complexity [29]

"*Order, vast and generative, arises naturally*" (S. A. Kauffman, 1995).

We are all, whether we know it or not, heavily influenced in our thinking and understanding of the world by reductionist thinking, the second law of thermodynamics – along with the idea that systems can be thought of as closed, close to equilibrium, and moving toward equilibrium – and Darwinism. In *At Home in the Universe*, Kauffman (1995) discusses the success of the reductionist approach to science over the last three centuries but notes its limitation in building a theory of the whole. Reductionism has no mechanism to explain properties that the complex whole exhibits, that cannot be explained by understanding the parts. These collective, emergent properties cannot be predicted by understanding the parts.

In contrast to reductionist science, one of the great challenges of complexity science is that it shows that specific long-term predictions cannot be made about the future of any complex system. Only short-term specifics and longer-term patterns can be predicted with any accuracy. For example, the weather for tomorrow can be fairly accurately predicted, but

[29] The content for much of this section was derived from Kauffman's (1995) *At Home in the Universe: The Search for Laws of Self-Organization and Complexity*. Page references in this section are to this book, unless otherwise noted.

for longer-term predictions, we have to rely on patterns. A very simple one being that it will be colder in the winter than in the summer (in the northern hemisphere). Another example of a pattern that can be predicted is that the frequency versus the magnitude of earthquakes will follow an inverse power law. We have no idea how large the next earthquake might be, but we can say that when we look at thousands of them, they will follow an inverse power law. There is law in the distribution of the size of earthquakes, but unpredictability in individual cases.

To understand complex systems, we also need to think in terms of dissipative systems, rather than closed thermodynamic equilibrium systems where, as Kauffman points out, "equilibrium is associated with collapse to the most probable, least ordered states" (p. 21). Dissipative systems are maintained by the continual dissipation of matter and energy. All living systems and the biosphere itself are dissipative – nonequilibrium – systems, where equilibrium means death. Therefore, modelling systems as closed equilibrium systems severely limits our ability to understand the world. This is not to say that a lot of work has not been done in trying to understand dissipative systems. Ever since Ilya Prigogine won a Nobel Prize for his work in understanding dissipative structures and their role in far-from-equilibrium thermodynamic systems, there has been a great deal of research in this area. But this view of the world has not propagated throughout our social and educational systems – deeply influencing the way we think about and perceive the world – the way Newtonian laws and the second law of thermodynamics have.

Darwinism is based on random variation, natural selection, and gradualism (evolution resulting from the very gradual accumulation of useful variations). Kauffman proposes that order is not accidental (that is, it is not random) and it is not gradual. He argues that laws of complexity "spontaneously generate much of the order of the natural world. It is only then that selection comes into play, further molding and refining" (p, 8). And the geologic record shows punctuated equilibrium (long periods of little to speciation or extinction, punctuated by periods of rapid change), which does not support the theory of gradualism. In the Cambrian explosion, there was a sudden proliferation of new classes, orders, families, etc. Kauffman points out that the fossil record shows that the rate of extinction and the formation of new species (speciation) vary, roughly, together. Extinctions occur in large and small 'avalanches' often initiated by large or small meteor strikes. He argues that it does not always take a meteor, or other cataclysm, to cause an extinction avalanche. Instead, he suggests:

> The very struggle to survive, to adapt to the small and large changes of one's coevolutionary partners, may ultimately drive some species to extinction while creating novel niches for others. Life, then, unrolls in an unending procession of change, with small and large bursts of speciations, and small and large bursts of extinctions. (p. 14-15)

This, Kauffman suggests, applies to the evolution of technology and social systems as well. He proposes that these systems evolve to a point between order and chaos; between structure and randomness. To a point where creativity and surprise can be expected. Where avalanches of change spread throughout a system as agents make their best choices "competing and cooperating to survive." Each new good or service provides opportunities for other goods or services to flourish while causing the decline or extinction of others. Schumpeter's creative destruction? Yes, but not in a pure *survival of the fittest* sense.

Kauffman uses the concept of fitness landscapes to help explain his theories of complexity as they apply to biological evolution. A fitness landscape helps to illustrate the evolution of an agent. Figure 6 below shows a fitness landscape with a search space that is only two dimensional. The evolving agent does not have a view of the overall landscape, only one square away in each direction, and they are always trying to maximize their fitness. Therefore, if an agent is in a flat area, they will wander until a hill is found. Once on a hill, they will proceed up it. If the hill does not happen to be the one with the highest peak, the evolving agent may get stuck on a local fitness peak, unless the agent has a search strategy that can find other fitness peaks.

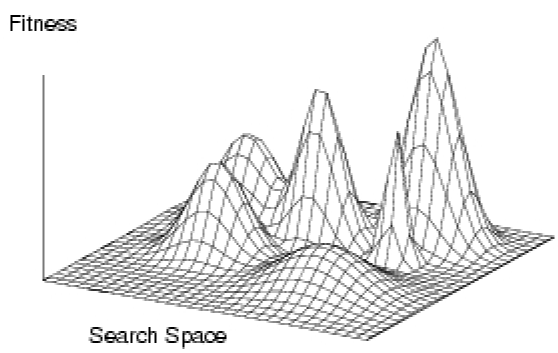


Figure 6: Fitness Landscape (source: https://www.biostars.org/p/86652/)

The concept of fitness landscapes is usually applied to populations, with the inheritance of useful traits helping to move the population up a fitness peak. In this case, random mutations are considered a search strategy that may land an individual on a higher fitness peak. When this happens, Darwinian Theory would suggest that the rest of the population is quickly pulled over to the higher fitness peak.

Figure 6 shows a possible fitness landscape for a system with two variables and, therefore, is shown in two dimensions. Consider humans with 19-20,000 genes, a simplistic view of genomics[30] would suggest a fitness landscape with 19-20,000 dimensions. In addition, the fitness landscape is constantly changing since the agent's coevolutionary partners are always adapting as well, and their adaptations change the landscape.

Pleuromona is the simplest free-living cell known and which can be considered to be alive. The number of genes in its genome is variously estimated at anywhere from a few hundred to about a thousand. It seems that this is the minimum amount of complexity required for life. Kauffman suggests this minimum level of complexity is "inherent to the very nature of life" (p. 42). But how does this minimum level of complexity required for life come about? The concept from a Darwinian perspective is that atoms randomly bump into each other and form molecules, molecules randomly bump into each other and form amino acids, and amino acids arrange themselves in random orders until one of those sequences forms an enzyme, then those enzymes must arrange themselves, by random happenstance, to form a living cell. Kauffman describes the work of Robert Shapiro who calculated that in the history of the earth there has been enough time for perhaps 2.5×10^{51} attempts to create life by chance. That sounds like a lot – until we consider that the odds of a successful attempt are estimated at about 1 in $10^{40.000}$. $10^{40.000}$ is an unfathomably large number. The total number of hydrogen atoms in the universe is estimated at 10^{60}. So, the odds of life happening by chance or essentially zero.

Kauffman offers an alternative view, what he calls order for free. His proposal is that:

---

[30] Current research suggests that the relationships between several genes are the determining factors for traits, rather than there being a one-to-one correlation between genes and traits. Introducing the epigenetic layer adds even more complexity to the picture.

> when the number of different kinds of molecules in a chemical soup passes a certain threshold, a self-sustaining network of reactions – an autocatalytic metabolism – will suddenly appear. Life emerged, I suggest, not simple, but complex and whole, and has remained complex and whole ever since. (p. 47-48)

Kauffman goes on to explain that:

> At its heart, a living organism is a system of chemicals that has the capacity to catalyze its own reproduction. Catalysts such as enzymes speed up chemical reactions that might otherwise occur, but only extremely slowly. What I call a collectively autocatalytic system is one in which the molecules speed up the very reactions by which they themselves are formed… What I aim to show is that if a sufficiently diverse mix of molecules accumulates somewhere, the chances that an autocatalytic system – a self-maintaining and self-reproducing metabolism – will spring forth becomes a near certainty. (p. 49 - 50)

This "order for free" theory is built on the principles of complexity theory and is explained, at least partially, by a model Kauffman developed called the NKp model. The NKp model is a way of working with and 'tuning' the fitness landscapes described above. As a starting point for understanding NKp models, we will consider a system of buttons and threads.

Imagine a large number of buttons – at least several thousand – scattered about on a floor. Now imagine connecting two randomly selected buttons with thread, then two more, and two more, and on and on. In time, you will eventually randomly select a button that was selected before, so that this button is now connected to two other buttons. In time, many of the buttons end up being connected in large clusters, while some are still not connected to any other buttons. Kauffman illustrates that as the ratio of threads to buttons is changed, the size of the largest cluster changes following an S-shaped curve and that there is a phase transition at the point where the ratio is 0.5 (see Figure 7).

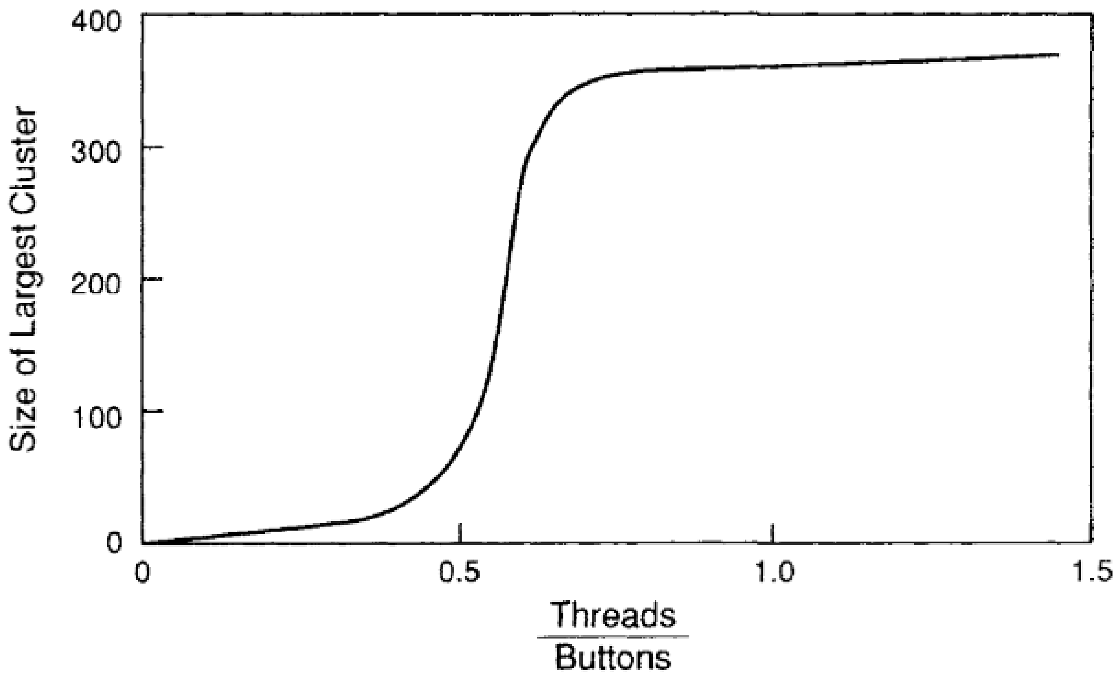


Figure 7: Cluster Size Phase Transition (Kauffman, 1995, p. 57)

Kauffman points out that the line at the ratio of 0.5 becomes steeper as the number of threads and buttons becomes larger and it becomes a discontinuity as the number of buttons approaches infinity. He then goes on to argue, as follows, that the phase transition in the size of the largest cluster is analogous to the emergence of life:

> The analogue in the origin-of-life theory will be that when a large enough number of reactions are catalyzed in a chemical reaction system, a vast web of catalyzed reactions will suddenly crystallize. Such a web, it turns out, is almost certainly autocatalytic-almost certainly self-sustaining, alive. (p. 58)

One of the conclusions of this argument is that a critical diversity of molecular species is necessary. Kauffman illustrates how there are more reactions that can form molecules than there are molecules themselves – more threads than buttons – therefore, life can snap into existence, whole. Which further explains why creatures have a minimum level of complexity. Another conclusion that Kauffman reaches is that any living system must strike a compromise between malleability and stability in order to survive in an environment that is constantly changing. To survive, a living system must be stable, but not so stable that it never changes. A living system must be changeable, but not so unstable that a slight internal fluctuation causes a feed-forward, harmonic-oscillator-type of effect that collapses the entire system.

Now we can move from buttons connected by threads as a metaphor for "a metabolic network of enzymes, substrates, and products" to a metaphor of a network of lightbulbs connected by wires. This metaphor leads to the NKp model, which has been used in many fields well beyond Kaufman's field of theoretical evolutionary biology. Here, we will think of a molecule catalyzing the formation of another molecule as one lightbulb turning on another lightbulb. And since a molecule can also inhibit the formation of another molecule, this is represented as one lightbulb turning another off.

The bulbs in this network have two possible states, on or off, which can be represented as 1 or 0. The number of possible combinations of bulbs that are on or off – ranging from all bulbs being off, to all bulbs being on, and everything in between – is called the state space. The state space – the number of possible combinations – is found by raising 2 to the power of the number of bulbs in the network. For a network of 1,000, the number of possible combinations is $2^{1,000}$, which is approximately equal to 1.07×10^{301}. That is, approximately, a one with three hundred zeros after it. It may be helpful to try to put that number into some sort of perspective by noting that the estimated number of atoms in the known, observable universe is between $1x10^{78}$ and $1x10^{82}$. In short, this is an unimaginably large number of possible combinations.

If there are N bulbs in the network, each one can be connected to anywhere from zero to N-1 other bulbs. The number of connections chosen for any particular model is called k. Together, these form Kauffman's now relatively famous NK model. The rule for whether each bulb turns on or off is typically based on the Boolean AND and OR operators. That is, a bulb could be told to turn on (at the next tick of the clock) when all of its inputs are 1, or when any one of its inputs are 1. Rules can also be created where a bulb turns on only when none of its inputs are 1, or when the percentage of inputs that are 1 is above, below, or equal to a certain threshold, or any other input condition we can think of.

While the state space may be large, the possible number of states is finite. If we start the system in one state, it will flow through a sequence of states, which is called a trajectory. Since the system is finite it will eventually reach a state it has previously been in and the trajectory will repeat and cycle forever around a recurring loop, called a state cycle. In the simplest event, the system would move immediately to a single pattern of 1s and 0s and stay there, "stuck in a cycle of length 1" (p.77). At the other end of the spectrum, the state cycle could go through every possible state in the state space. In a network of 1,000 bulbs, "If the network were on a state cycle passing through every one of this hyperastronomical number of states, and if it took a mere trillionth of a second per state transition, we could never in the lifetime of the universe see the system complete its orbit" (p. 77-78). If the state cycle is small, it has a very orderly pattern. If the state cycle is very large, it appears – and is, from any human perspective – random.

Two features of these networks control whether they are ordered, chaotic, or in the phase transition between the two. One is the number of connections between bulbs. If each bulb is controlled by only one or two other bulbs, the system will be highly ordered. If each bulb is controlled by many other bulbs, the system is chaotic. So, the system can be 'tuned' by adjusting K – the number of connections between each bulb.

A K=1 system will not produce anything interesting, while a K=N system will result in a state cycle that is the square root of the number of states. For the 1,000-lightbulb network discussed earlier, the state cycle – the number of steps from the beginning until the pattern starts to repeat – is approximately 2.3×10^{65}. Even if this system progressed at a step each one billionth of a second, and if it started 15 billion years ago when our universe was just beginning to form, it would still be many, many trillions of years away from starting to repeat. In this case, the system has been pulled into a state cycle attractor that is so long, we would never be able to recognize it as an attractor. This is a chaotic system. In fact, even when K is much less than N – say K=4 or K=5 – the system will exhibit unpredictable, chaotic behaviour, similar to the K=N system. But things change suddenly when K=2. Kauffman explains it as follows:

> Think of a randomly constructed Boolean network with N = 100,000 lightbulbs, each receiving K = 2 inputs… Each lightbulb has also been assigned at random a Boolean function. The logic is, therefore, a similar mad scramble, haphazardly assembled, mere junk. The system has $2^{100,000}$ or $10^{30,000}$ states – megaparsecs of possibilities – and what happens? The massive network quickly and meekly settles down and cycles among the square root of 100,000 states, a mere 317. Thus such systems do not show sensitivity to initial conditions; they are not chaotic. The

consequence is the homeostasis we seek. Once such a network is on an attractor, it will return to the same attractor with very high probability if it is perturbed. (p. 83)

Bernard Derrida and Gerard Weisbuch showed that NK networks with K greater than 2 can be tuned to make a chaotic network become orderly with the addition of a variable called p. p is a parameter which biases the output of a Boolean logic table toward all 1s or all 0s. When p=.5 the network will behave as a pure NK network. When p=1 there is 100% bias for bulbs to be on and all outputs will be 1. When p=0, there is a 100% bias for bulbs to be off and all outputs will be 0. Thus, there are two ways – by adjusting K, or p – in which networks can be driven toward the complexity zone, between order and chaos. This is the zone where things are orderly enough to ensure sufficient stability, yet it is a zone where there is enough flexibility that surprises can and will happen. It's where the fun is. Kauffman argues that all living cells must be capable of this orderly-yet-flexible behaviour, therefore evolution takes us to the zone of complexity, between order and chaos. Cells – or organisms – that move too far into the ordered or chaotic zones will die. We live in the complexity zone, and we only exist because we are there – that zone where surprising things can and will happen.

The NKp model can be used to define a fitness landscape where N is the number of factors which can contribute to fitness (genes when modelling evolutionary biology) and K is the number of interconnections between contributions (again, when modelling evolutionary biology, this is the number of epistatic linkages between genes). Larger K will lead to a greater number of local maxima – a rougher landscape – while p can be applied to dampen this roughness or exacerbate it.

Kauffman moves on to theorize how the biosphere evolves, naturally, to a subcritical-supracritical boundary where large and small bursts of molecular creativity can take place, similar to Bak's large and small avalanches. This is, again, the phase transition between order and chaos, and it is markedly different from Darwin's gradualism but is more consistent with the known fossil record.

I will leave this summary of Kauffman's work with one last quote, which neatly summarizes his multiple theories: "Our intuitions about the requirements for order have, I contend, been wrong for millennia. We do not need careful construction; we do not require crafting. We require only that extremely complex webs of interacting elements are sparsely coupled" (p. 84).

2.3.4 Signals and Boundaries: Building Blocks for Complex Adaptive Systems[31]

John Holland introduced and developed the field of genetic algorithms in the 1970s. He also developed the field of computational evolution (Robilliard, 2013). This work led him to a long career as a complexity theorist. Holland was a founding member of the Santa Fe Institute and the founder of the Center for the Study of Complex Systems ("Complexity science giant John Holland passes away at 86," 2015).

In *Complexity: A Very Short Introduction*, Holland (2014) avoids proposing a rigorous definition of complexity. Rather, he claims there isn't one. However, Holland lists the most common behaviours of complex systems as self-organization, chaotic behaviour, 'fat-tailed' behaviour, adaptive interaction and emergence.

[31] The content for much of this section was derived from Holland's (2012) *Signals and Boundaries: Building Blocks for Complex Adaptive Systems*. Page references in this section are to this book, unless otherwise noted.

Self-organization, also called spontaneous order, is seen when complex patterns occur as a result of multiple agents following simple rules, such as flocks of birds or schools of fish. That is, the local interactions of an initially disordered system results in overall order without any external control. Chaotic behaviour is also referred to as sensitive dependence on initial conditions. This has come to be known, in popular culture, as the butterfly effect. Small changes in initial conditions (a butterfly flapping its wings in Argentina) can result in large subsequent changes (a hurricane in Japan). Fat-tailed behaviour is the result of systems that follow an inverse power law rather than a normal distribution. That is, rare events, such as mass extinctions, massive earthquakes, hurricanes, tsunamis, landslides, or market crashes, occur much more often than would be predicted based on normal distributions. Adaptive interactions occur when interacting agents change their strategies as they accumulate experience. That is, agents try different strategies to achieve fitness as they accumulate knowledge about other agents and their environment. Investors, for instance, may change their investment strategy depending on how the overall stock market is moving, current economic and political news, and what they think other investors will do. Individual agents influence the overall market movement, while the overall market movement influences individual agents.

Holland suggests that emergence helps to distinguish complex systems from other systems. Emergence is defined as the interaction of individual agents resulting in aggregate properties not attained by summation of the properties of the individual agents – the aggregate properties being the emergent properties and emergent behaviour. That is, the interactions are non-linear and result in levels of organization and hierarchies, "selected aggregates at one level become 'building blocks' for emergent properties at a higher level"

(Holland, 2014, p. 4). Thus, emergence is closely associated with hierarchical levels, with each level governed by its own set of laws.

Holland goes on to differentiate between complex physical systems (CPS) and complex adaptive systems (CAS). As the name implies, complex physical systems are concerned with physical systems. Complex physical systems consist of elements with fixed properties, interacting directly only with physically close neighbours. Because they have fixed properties, they have no way to learn, grow, or adapt. Complex adaptive systems, on the other hand, have elements that are not fixed. The elements, called agents, change, learn, and adapt as a result of interactions with other agents and their environment. As Holland notes, since each agent is adapting its strategy to the strategies of all the other agents, it would be unusual for a complex adaptive system to converge on a single optimal strategy or an equilibrium.

Holland's work with signals and boundaries is only concerned with complex adaptive systems. In *Signals and Boundaries: Building Blocks for Complex Adaptive Systems Holland* (2012) takes on the ambitious goal of developing a general purpose model applicable to, and useful for, studying all complex systems. Holland contends that "Ecosystems, governments, biological cells, markets, and complex adaptive systems, in general, are characterized by intricate hierarchal arrangements of boundaries and signals" (p. 1).

Holland argues that all complex adaptive systems have internal boundaries that divide the system into "semi-autonomous subsystems called *agents*" (p. 290). Each agent follows relatively simple rules – a program – that determines how it interacts with other agents and its environment. The boundaries are semi-permeable and anything passing through, or attempting to pass through the barrier, is considered a signal. When a signal passes through a semi-permeable barrier it can have the effect of modifying the systems' behaviour.

Holland models an evolving signal/boundary system with *tags*, *tagged urns*, *classifier systems, genetic algorithms and dynamic generated systems*. A tag in this model refers to a signal (resource) identifier that may match other tags sufficiently to allow passage through a boundary according to a programmed rule or may interact with other signals based on the programming of their respective tags. Tags, and parts of tags, become building blocks that are recombined through genetic algorithms to create new signals and rules. Holland makes use of and extends the *urns and coloured balls model* frequently used in probability theory. The primary extension of this model is the addition of a tag on each urn which acts as a semi-permeable membrane, allowing coloured balls (signals/resources) to enter or leave only if they meet certain rules programmed into the tag. Also, the balls can interact according to the rules of their own tags. The rules of both the barriers (tagged urns) and the signals (tagged, coloured balls), coevolve based on the classifier system. A classifier system includes a discovery component – the genetic algorithm – and a learning component, based on attaining higher fitness levels. In this model, fitness is reproductive fitness, in this case meaning the ability to collect all the elements required to reproduce all the tags used in all of the agent's urns and signals. The definition of classifier systems is elaborated on by Booker, Goldberg, and Holland (1989)

> Classifier systems are massively parallel, message-passing, rule-based systems that learn through credit assignment (the bucket brigade algorithm) and rule discovery (the genetic algorithm). They typically operate in environments that exhibit one or more of the following characteristics: (1) perpetually novel events accompanied by large amounts of noisy or irrelevant data; (2) continual, often real-time, requirements

> for action; (3) implicitly or inexactly defined goals; and (4) sparse payoff or reinforcement obtainable only through long action sequences. Classifier systems are designed to absorb new information continuously from such environments, devising sets of competing hypotheses (expressed as rules) without disturbing significantly capabilities already acquired. (p. 235)

This is accomplished through the cross-breeding of tags in a way that supports a balance between exploitation and exploration (Mitchell, 2009). Holland illustrates how a single-point crossover between two tags (in this case, think of the tag as being a genetic sequence) will yield one offspring that is most likely made up of proven building blocks (exploitation) while the other is more likely to be a random combination (exploration). Elaborating on this point, he notes that "because complex adaptive systems are organized around populations, both offspring options can be explored without abandoning advantages already attained by the parents" (p. 284). He also notes that progressive cross-breeding of this type will produce both generalist and specialist agents, moving toward a ratio that is most suitable to the current environment, which, of course, is constantly changing.

Holland shows how a wide range of complex adaptive systems, from governments to biological cells and from rainforests to financial markets can be modelled as agent-based signal/boundary systems, and that all share the same general features:

> "semi-autonomous subsystems (agents)
> hierarchical organization (agents composed of agents)
> sustained diversity (agents exploiting different strategies)
> extensive recycling of resources (agents converting resources
> and passing them on)" (p. 289).

2.3.5 Complexity and Creativity in Organizations[32]

Stacey (1996) claims that traditional management science has failed because it assumes organizations are systems that tend toward a stable equilibrium and that this reductionist thinking has led us to do exactly the wrong thing in many instances. He argues that we can make more progress by recognizing that organizations are complex systems and by analyzing them accordingly. He points out that organizations fall into that particular area of complexity science known as complex adaptive systems and defines them as follows:

> The science of complexity studies the fundamental properties of nonlinear-feedback networks and particularly of complex adaptive networks. Complex adaptive systems consist of a number of components, or agents, that interact with each other according to sets of rules that require them to examine and respond to each other's behavior in order to improve their behavior and thus the behavior of the system they comprise. In other words, such systems operate in a manner that constitutes learning. Because those learning systems operate in environments that consist mainly of other learning systems, it follows that together they form a coevolving suprasystem that, in a sense, creates and learns its way into the future. (p. 10)

In other words, in the organizational context, what one person does and says is dependent on what those around him/her do and say, and what each of them does and says is dependent on what the first person, and everyone else, does and says. The behaviours and

---

[32] The content for much of this section was derived from Stacey's (1996) *Complexity and Creativity in Organizations*. Page references in this section are to this book, unless otherwise noted.

actions of each person are continually adapting based on the behaviours and actions of every other person in the organization and outside of the organization, with each person (agent) learning along the way, adapting in ways that will benefit them and, possibly, their organization and/or colleagues. Negative feedback is employed by the organizations "legitimate system", a deterministic set of rules designed to propel the organization in a predetermined, strategic direction. In a creatively evolving organization, this is balanced by the positive feedback loops of the "shadow system", a system of unwritten norms, behaviours and communication channels that evolves in the interstices between elements making up the legitimate system.

> Any stability in the emergent irregular patterns is produced by the tension between negative and positive feedback, in which one provokes while the other restrains… The system's specific behavior cannot be designed or controlled; instead, that behavior emerges. Because these causal links are lost, long-term predictability of specific outcomes is impossible. Note that I am not saying that no causal links exist. They are there but they cannot be traced either backward or forward in time. (p. 66 - 67)

Stacey uses complexity science to challenge the classic management science approaches to prediction and control. He says that we are not doomed to anarchy when we cannot predict and control the outcome of every action. On the contrary, he claims these are the conditions required for creative evolution. He shows how and why we can't reliably predict and control what happens in the future and implies that we might as well admit it, get used to it, and start controlling what we can – the factors that influence the likelihood of creative evolution. The price for this freedom to evolve is that we can't know the final destination, and we aren't even in control of the journey. In his words:

> A system occupies the space for endless variety, novelty, and creativity only at critical points in parameter values with enough disorder to prevent the system from becoming trapped in some local equilibrium to the detriment of its long-term development to higher fitness peaks, but also with sufficient containing structure and order to prevent it from falling apart into patternless behavior (p. 99).
>
> What determines whether an organization is at the edge or not? What pushes it from the stable zone, through the edge of chaos, and into the unstable zone? In other words, what are the control parameters? There seem to be five: the rate of information flow, the degree of diversity, the richness of connectivity, the level of contained anxiety, and the degree of power differentials (p. 179).

As can be seen with many factors that have been associated with creativity, each of these control parameters requires just the right balance. Too much or too little of any one of the five will push the organization – or, more generally, the system – away from the edge of chaos, out of the creative zone. That is, a system needs a critical amount of information flow in order to reach 'the zone.' Too little and the system will freeze into a highly structured, rigid organization that finds it impossible to do anything novel. Too much and the system devolves into a world where nothing gets done due to endless options and continual analysis.

Similarly, too little diversity, connectivity, and contained anxiety will result in too much structure, with little to no novelty. Too much of these parameters results in little to no novelty due to extreme disorder. On the other hand, too much of a variance in power –

from the top of the organization to the bottom – results in an autocratic, too-rigid structure. While too little power variation results in a directionless organization that makes no progress.

Stacey summarizes the properties of adaptive nonlinear feedback networks as follows.

I A space for creativity

- A phase transition between stability and instability at the edge of system disintegration
- A state of paradox
- Actualization of archetypes
- Creative destruction
- A critical point for the control parameters of energy and information flow, agent connectivity, schema diversity

II The sources of instability

- Amplification of tiny changes
- Competition
- Exposure to creative tension set up by play in recessive schemas

III The sources of stability

- Constraint
- Cooperation and redundancy
- Protection from creative tension by dominant schemas

IV Dialectical evolution

- Small incremental, progressive changes are a poor learning strategy but tension between contradictory forces provokes more effective learning

V Causality and predictability

- Specific long-term evolution is radically unpredictable but archetypal patterns and short-term changes are predictable (p. 105).

2.3.6 The Nature of Technology: What it is and How It Evolves [33]

In *The Nature of Technology: What it is and How it Evolves*, Arthur (2009) builds a theory of technology by looking at it from the perspective of complexity science. More precisely – since there are many different perspectives of complexity science – he views it from the perspective of complexity science, as it applies to theoretical biological evolution. He points out that, while we know much about individual technologies, we do not have a good understanding of technology in a more general sense.

Ever since Darwin's *Origin of Species*, according to Arthur, there have been people applying the concept of evolution to technology. This began four years after Darwin's landmark publication with Samuel Butler's book *Darwin Among the Machines*. While Butler pointed out the need for a theory, by 1935 Gilfillan had traced the line of descent of various ship technologies. However, Arthur argues that this "is 'evolution' in the narrow sense of gradual development: the descent of form" (p. 15). He points out the need for an argument that all technologies are descendants of earlier technologies. A theory of technology must, he claims, provide this argument as well as a mechanism by which it happens. It must explain not just incremental development, but the seemingly abrupt, or discontinuous, radical novelty.

In order to build a theory of technology, we must, of course, define what we mean by 'technology.' Arthur provides three definitions: "a means to fulfil a human purpose… an assemblage of practices and components… [and] the entire collection of devices and engineering practices available to a culture" (p. 27).

[33] The content for much of this section was derived from Arthur's(2009) *The Nature of Technology: What it is and How it Evolves*. Page references in this section are to this book, unless otherwise noted.

Arthur reveals that all new technologies that he has investigated were "created-constructed, put together, assembled-from previously existing technologies" (p. 2). That is, they were combinations of other technologies. Each technology from the past can be a building block for current and future technologies. Just as all current technologies can be building blocks for future technologies. This leads to an ever-increasing supply of building blocks, which can lead to an ever-accelerating advancement of technology, just as envisioned in Moore's law and the technological singularity (Kurzweil, 2005). However, if we go back to the first technologies, we have to ask where they came from. Arthur refers to "bow-drills and pottery-firing techniques" (p. 22) as possible initial technologies. I think stone choppers and controlled fire may provide better examples of primordial technologies. However, no matter what the earliest technologies were, a theory of new technologies being derived from existing technology building blocks is incomplete if it can't conceptualize where the first technologies came from. In his words: "Something else, something more than mere combination, must be going on to create novel technologies" (p. 22). His answer? "That something else, I will argue, is the constant capture of new natural phenomena and the harnessing of these for particular purposes" (p. 22).

The core argument in *The Nature of Technology* is made up of three parts: all technologies are combinations; each component of a technology is itself a technology; and all technologies make use of one or more effects or phenomena. However, as mentioned above, Author embeds this in a complexity science framework. For instance, he points out how new products and processes get improved with use and adoption. More use leads to more improvements, which leads to more adoption and more use in a positive feedback loop. If two products compete, and if one manages to gain a small lead over the other, this small lead may be amplified, through this positive feedback loop, until that product dominates the market. Arthur argues that before this positive feedback loop gets started, there is no way to know which product may turn out to be the winner, it could be either one. In his theory, random events which may, over time, be magnified by positive feedback loops, could result in either product emerging as the dominant technology. In other words, Arthur is applying the concept of *sensitive dependence on initial conditions* to the evolution of technology.

In his theory, methods and processes are viewed as technologies, and every technology has at its core an effect or phenomenon. A simple example is that the hammer makes use of the transmission of momentum. In this sense, "a technology is a phenomenon captured and put to use" (p. 51). Frequently the technology is based on a complex set of interacting phenomena.

Arthur and his co-researcher Pollack set up a computer simulation to model technological evolution with logic circuits. The simulation began with only the simplest logic circuit available as a building block – a NAND (Not AND) circuit. This simulated world was given a wish list of functions that its imagined 'inhabitants' would like to perform – AND, OR, Exclusive-OR's, 3-bit addition, 4-bit additions, and similar functions. They found that complicated 'technologies' would never evolve without less complicated technologies evolving first. They also found that there were large gaps of time where nothing of significance happened, followed by bursts new technology; once a key technology was developed, it could be used as the basis for many more complex technologies. In addition, they found that technological evolution was history-dependent, that superior technologies replaced previous ones in avalanches of destruction, and that the near-term prediction of technological evolution was predictable, but further out in time indeterminacy increases exponentially. All as would be expected of a complex system.

Another feature of this model, as pointed out by Arthur, is its "circular causality… Technology creates the structure of the economy, and the economy mediates the creation of novel technology (and therefore its own creation)" (p. 194). This can be viewed as another aspect of complexity in that the economy is an emergent property of the interaction among individuals. In a complex system, we can expect the individual to influence the emergent property (in this case, the economy) and the emergent property (economy) to influence the individual. In this case, the individual, or groups of individuals, are motivated to solve problems (create technologies) for economic, or societal (another emergent property) reasons.

2.3.7 Common Elements of Complexity

Each of the authors discussed in the previous sections emphasized different aspects of complexity science, while also having areas of commonality. The following is a quick recap of some of the salient points each author discussed and ascribes to complexity.

Bak: self-organization, self-organized criticality, far from equilibrium, self-similarity and scale independence, fat-tailed behaviour, and emergence.

Stuart Kauffman: self-organization, diversity is necessary, a balance between stability and dynamism is required for complex adaptive systems, the number of interconnections between agents determines whether a system is ordered or chaotic, and learning or adaptive.

Holland: self-organization, chaotic behaviour, 'fat-tailed' behaviour, adaptive interaction and emergence, hierarchical organization, learning or adaptive, and sensitive dependence on initial conditions.

Stacey: far from equilibrium, learning, opposing forces create a space for creativity (the rate of information flow, the degree of diversity, the richness of connectivity, the level of contained anxiety, and the degree of power differentials); Amplification of tiny changes (sensitive dependence on initial conditions)

Arthur: Building blocks of previous technologies and natural phenomena, the strong get stronger through more use with more feedback and evolutionary tweaks (a positive feedback loop), sensitive dependence on initial conditions, punctuated equilibrium, path dependence, near-term predictability while the longer term is unpredictable, and hierarchical interaction.

The following is a summary of some of the important terms and concepts common to many complexity theories.

Self-organized criticality occurs when systems evolve to a point where 'avalanches' of virtually any size are possible. The frequency distribution of these avalanches follows an inverse power law along with its characteristic fat-tailed behaviour.

Fat-tailed behaviour in a system means there is a greater likelihood of extreme events than there is in a system that follows a Gaussian distribution.

Sensitive dependence on initial conditions is related to self-organized criticality. Consider the sand pile: the size of the next avalanche is dependent on the orientation of every grain of sand and its relationship to all the grains around it. A minor reorientation of one grain of sand could change the result from the next grain of sand dropped.

Patterns are expected, but specific events cannot be predicted: For example, there is law in the distribution of the size of earthquakes, but unpredictability in individual cases.

Self-similarity is the property of an object being the same, or similar to, a part of itself. When viewing an object with self-similarity, zooming in or zooming out will present a similar view.

Emergence is the higher order (complex) output resulting from the interaction of many lower order (simple) inputs. To put it another way, the interaction of many simple elements can result in complex, unpredictable patterns, in lower-order systems, through to intelligent, adaptive behaviour in higher order systems. Examples of higher order emergence include intelligent behaviour in ant colonies and in the brain, as a result of the interactions of, respectively, thousands of ants or trillions of neurons.

2.3.8 Criticisms

Horgan (1995), has criticized complexity theory, saying it is unlikely to yield any useful general principles and that it is a "fact free science" because of its dependence on computer modelling. Horgan also criticizes complexity science for being too grandiose and trying to apply to everything. He quotes Crutchfield, a complexity science researcher at the Santa Fe Institute, as saying "If a theory applies to everything, it may really apply to nothing" (p. 108).

Michael White (2010), agrees with Horgan's criticisms, adding that the attempts of complex system researchers to apply universal principles to different systems are sometimes "awkward" and that "they not only ignore system-specific details they deem irrelevant but fail to actually learn what they're ignoring."

Mitchell (2009) counters Horgan's criticisms but does admit that coming up with a set of general principles that apply to all complex systems may be unrealistic. She suggests instead that searching for common principles may be more appropriate.

Despite these criticisms, complex adaptive systems theory seems to have significant explanatory power across many fields. It even appears to be possible to use it to explain topics which have thus far stubbornly defied explanation, such as creativity.

While some common themes have been extracted from the authors reviewed in this section, it is a challenging task to do so. Each author approaches the subject of complexity from the perspective of their own field. The result is a wide variety of terminology and perspectives that make it seem as though each author is writing about an entirely different topic. The perspectives represented in this section include theoretical biological evolution, physics, economics, and computer science/information theory. A common framework and lexicon would help improve communication and research within this important interdisciplinary field. While the Santa Fe Institute has made progress with a lexicon, it's members (most of the researchers reviewed in this section are associated with the Santa Fe Institute) are far from a common framework. Chapter 5 of this dissertation presents an initial model that could provide a framework for future research and communication.

Bibliography[34]

A Little History. (2013). Retrieved November 23, 2013, from http://www.creativeeducationfoundation.org/about-us/brief-history

Adamic, L. A. (n.d.). Zipf, Power-law, Pareto - a ranking tutorial. Retrieved February 19, 2017, from http://www.labs.hp.com/research/idl/papers/ranking/ranking.html

Albert, R. S., & Runco, M. A. (1999). A History of Research on Creativity. In *Handbook of Creativity* (pp. 16–31). New York, NY: Cambridge University Press.

Amabile, T. M. (1977). *Effects of extrinsic constraint on creativity*. Stanford University. Retrieved from http://search.proquest.com/docview/302845439?

Amabile, T. M. (1996). *Creativity in context: Update to the social psychology of creativity*. Boulder, CO: Westview Press.

Amabile, T. M., & Pillemer, J. (2012). Perspectives on the Social Psychology of Creativity. *Journal of Creative Behavior*, *46*(1), 3–15. https://doi.org/10.1002/jocb.001

Amabile, T. M., & Pratt, M. G. (2016). The dynamic componential model of creativity and innovation in organizations: Making progress, making meaning. *Research in Organizational Behavior*. https://doi.org/10.1016/j.riob.2016.10.001

Anderson, P. W. (2008). Complexity: 5 questions. In C. Gershenson (Ed.) (pp. 5–8). [S.l.]: Automatic Press.

André, P., Schraefel, M. C., Teevan, J., & Dumais, S. T. (2009). Discovery is never by chance: Designing for (un)serendipity. In *Proceeding of the seventh ACM conference on*

[34] This bibliography is for chapters 1 and 2 only. There are separate bibliographies for each article and the final chapter.

Creativity and cognition - C&C '09 (p. 305). New York, New York: ACM Press. https://doi.org/10.1145/1640233.1640279

Andriani, P., & McKelvey, B. (2007). Beyond Gaussian averages: redirecting international business and management research toward extreme events and power laws. *Journal of International Business Studies*, *38*(7), 1212.

Arthur, W. B. (2008). Complexity: 5 questions. In C. Gershenson (Ed.) (pp. 9–14). [S.l.]: Automatic Press.

Arthur, W. B. (2009). *The nature of technology: What it is and how it evolves*. New York, NY: Free Press.

Baer, J. (1998). The case for domain specificity of creativity. *Creativity Research Journal*, *11*(2), 173–177.

Baer, J. (2010). Is creativity domain specific? In J. C. Kaufman & R. J. Sternberg (Eds.), *The Cambridge Handbook of Creativity* (pp. 321–341). New York, NY: Cambridge University Press.

Bain, A. (1868). *The senses and the intellect.* (Vol. 2). London, UK: Longmans, Green, and Company.

Bak, P. (1996). *How nature works: The science of self-organized criticality*. New York, NY: Copernicus.

Baker, J. B. (2007). *Beyond Schumpeter vs. Arrow: How Antitrust Fosters Innovation*. Retrieved from https://conference.nber.org/conferences/2007/si2007/PRIPE/baker.pdf

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological Review*, *84*(2), 191–215. Retrieved from https://www.uky.edu/~eushe2/Bandura/Bandura1977PR.pdf

Bar-Yam, Y. (2011). Concepts: Power Law. Retrieved February 19, 2017, from http://www.necsi.edu/guide/concepts/powerlaw.html

Barseghyan, H., Overgaard, N., & Rupik, G. (2018). Newtonian Worldview. In *Introduction to History and Philosophy of Science*. Pressbooks. Retrieved from http://hakobsandbox.openetext.utoronto.ca/part/chapter-9/

Basadur, M., Taggar, S., & Pringle, P. (1999). Improving the measurement of divergent thinking attitudes in organizations. *Journal of Creative Behavior*, *33*. https://doi.org/10.1002/j.2162-6057.1999.tb01040.x

Becker, M. (1995). Nineteenth-Century Foundations of Creativity Research. *Creativity Research Journal*, *8*(3), 219–229. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=7425015&site=ehost-live&scope=site

Beghetto, R. A. (2005). Does Assessment Kill Student Creativity? *Educational Forum, The*, *69*(2), 254–263.

Benton, M. J., & Harper, D. A. T. (2009). *Introduction to paleobiology and the fossil record*. Hoboken, NJ: Wiley-Blackwell.

Bethune, G. W. (1837). *Genius: An Address Delivered Before the Literary Societies of Union College*. Philadelphia, PA: G.W. Mentz and Sons. Retrieved from http://babel.hathitrust.org/cgi/pt?id=hvd.hwjsvt

Birdi, K., Leach, D., & Magadley, W. (2012). Evaluating the impact of TRIZ creativity training: an organizational field study. *R & D Management*, *42*(4), 315.

Blair, C. S., & Mumford, M. D. (2007). Errors in Idea Evaluation: Preference for the Unoriginal? *Journal of Creative Behavior*, *41*(3), 197–222.

Booker, L. B., Goldberg, D. E., & Holland, J. H. (1989). Classifier systems and genetic algorithms. *Artificial Intelligence*, *40*(1), 235–282.

Brynjolfsson, E. (1993). The Productivity Paradox of Information Technology. *Commun. ACM*, *36*(12), 66–77. https://doi.org/10.1145/163298.163309

C T I Reviews. (2016). *The Cognitive Sciences, An Interdisciplinary Approach*. Cram101.

Campbell, D. T. (1960). Blind variation and selective retention in creative thought as in other knowledge processes. *Psychological Review*, *67*(6), 380–400. https://doi.org/10.1037/h0040373

Carlozzi, A. F., Bull, K. S., Eells, G. T., & Hurlbut, J. D. (1995). Empathy as related to creativity, dogmatism, and expressiveness. *The Journal of Psychology*, *129*(4), 365–373.

Carson, S. (2010). *Your creative brain: Seven steps to maximize imagination, productivity, and innovation in your life*. San Francisco, CA: Wiley.

Cave painting. (2016, November 17). Retrieved November 20, 2016, from https://en.wikipedia.org/wiki/Cave_painting

Christensen, C. M. (1992). Exploring the Limits of the Technology S-Curve. Part I: Component Technologies. *Production and Operations Management*, *1*(4), 334–357. https://doi.org/10.1111/j.1937-5956.1992.tb00001.x

Christensen, C. M. (1997). *The innovator's dilemma: When new technologies cause great firms to fail.* Boston, MA: Harvard Business Review Press.

Christensen, C. M., & Raynor, M. (2003). *The innovator's solution: Creating and sustaining successful growth*. Boston, MA: Harvard Business School Press.

Cognition. (2013). Retrieved November 27, 2016, from https://en.wikipedia.org/wiki/Cognition

Cohen, P. S. (2000). The dilemma of the "Innovator's Dilemma": Clayton Christensen's management theories are suddenly all the rage, but are they ripe for disruption? *Industry Standard*, (January 10).

Complex. (2016). Retrieved November 26, 2016, from http://www.merriam-webster.com/dictionary/complex

Complexity science giant John Holland passes away at 86. (2015). Retrieved April 17, 2017, from https://www.santafe.edu/news-center/news/in-memoriam-john-holland

Conti, R., Coon, H., & Amabile, T. M. (1996). Evidence to support the componential model of creativity: Secondary analyses of three studies. *Creativity Research Journal*, *9*(4), 385–389. https://doi.org/10.1207/s15326934crj0904_9

Cramond, B. (1994). We Can Trust Creativity Tests. *Educational Leadership*, *52*(2), 70–71.

Creative Problem Solving. (2016). Retrieved December 3, 2016, from http://www.creativeeducationfoundation.org/creative-problem-solving/

Crick, F. (1996). The Impact of Linus Pauling on Molecular Biology. Retrieved November 27, 2016, from http://oregonstate.edu/dept/Special_Collections/subpages/ahp/1995symposium/crick.html

Csikszentmihalyi, M. (1988). Society, culture, and person: a systems view of creativity. In R. J. Sternberg (Ed.), *The nature of creativity: Contemporary psychological perspectives* (pp. 325–339). New York, NY: Cambridge University Press.

Csikszentmihalyi, M. (1990). The domain of creativity. In M. A. Runco & R. S. Albert (Eds.), *Theories of Creativity* (pp. 190–212). Newbury Park, CA: Sage Publications, Inc.

Csikszentmihalyi, M. (1996). *Creativity: Flow and the Psychology of Discovery and Invention*. New York, NY: HarperCollins Publishers.

Dacey, J. (2011). Historical Conceptions of Creativity. In *Encyclopedia of Creativity* (2nd ed., pp. 608–616). Elsevier, Inc.

Danneels, E. (2004). Disruptive technology reconsidered: A critique and research agenda.

The Journal of Product Innovation Management, *21*(4), 246–258. https://doi.org/10.1111/j.0737-6782.2004.00076.x

David, P. A. (1990). The Dynamo And The Computer: An Historical Perspective On T. *The American Economic Review*, *80*(2), 355.

De Vany, A. (2006). The Movies. In V. A. Ginsburgh & D. Throsby (Eds.), *Handbook of the Economics of Art and Culture*. Boston, MA: Elsevier.

Dean, L. G., Kendal, R. L., Schapiro, S. J., Thierry, B., & Laland, K. N. (2012). Identification of the Social and Cognitive Processes Underlying Human Cumulative Culture. *Science*, *335*(6072). https://doi.org/10.1126/science.1213969

Downes, L., & Nunes, P. (2013). Big-bang disruption. *Harvard Business Review*, (March). Retrieved from https://hbr.org/2013/03/big-bang-disruption/

Downes, L., & Nunes, P. (2014). *Big Bang Disruption: Business Survival in the Age of Constant Innovation*. New York, NY: Penguin Books Limited.

Dunning, D. (2005). Self-insight : roadblocks and detours on the path to knowing thyself. New York, NY: Psychology Press.

Dyer, J., Gregersen, H. B., & Christensen, C. M. (2011). *The innovator's DNA: Mastering the five skills of disruptive innovators*. Boston, MA: Harvard Business Press.

Edmonds, B. (2008). Complexity: 5 questions. In C. Gershenson (Ed.) (pp. 45–50). [S.l.]: Automatic Press.

Emre, M. (2018). *The Personality Brokers: The Strange History of Myers-Briggs and the Birth of Personality Testing*. New York, NY: Doubleday, a division of Penguin Random House LLC.

Eysenck, H. J. (1993). Creativity and Personality: Suggestions for a Theory. *Psychological Inquiry*, *4*(3), 147–178. https://doi.org/10.1207/s15327965pli0403_1

Eysenck, H. J. (1995). *Genius: The Natural History of Creativity*. Cambridge, UK: Oxford University Press.

Feist, G. J. (1998). A meta-analysis of personality in scientific and artistic creativity. *Personality and Social Psychology Review*, *2*(4), 290–309.

Feist, G. J. (2010). The function of personality in creativity: The nature and nurture of the creative personality. In J. C. Kaufman & R. J. Sternberg (Eds.), *The Cambridge Handbook of Creativity* (pp. 113–130). New York, NY: Cambridge University Press.

Feldhusen, J. F., & Clinkenbeard, P. R. (1986). Creativity Instructional Materials: A Review of Research. *The Journal of Creative Behavior*, *20*(3), 153–182.

Feldhusen, J. F., Speedie, S. M., & Treffinger, D. J. (1971). The Purdue creative thinking program: Research and evaluation. *NSPI Journal*, *10*(3), 5–9. https://doi.org/10.1002/pfi.4180100304

Feldhusen, J. F., Treffinger, D. J., & Bahlke, S. J. (1970). Developing Creative Thinking: The Purdue Creativity Program. *The Journal of Creative Behavior*, *4*(2), 85–90.

Fink, A., & Neubauer, A. C. (2006). EEG alpha oscillations during the performance of verbal creativity tasks: Differential effects of sex and verbal intelligence. *International Journal of Psychophysiology*, *62*(1), 46–53. https://doi.org/10.1016/j.ijpsycho.2006.01.001

Florida, R. L. (2012). *The rise of the creative class revisited*. New York: Basic Books.

Fractal. (2017). Retrieved February 19, 2017, from https://www.merriam-webster.com/dictionary/fractal

French, S. (2007). *Science: Key Concepts in Philosophy*. Bloomsbury Academic.

Gabora, L. (2011). An Analysis of the Blind Variation and Selective Retention Theory of Creativity. *Creativity Research Journal*, *23*(2), 155–165. https://doi.org/10.1080/10400419.2011.571187

Gangadharbatla, H. (2010). Technology Component: A Modified Systems Approach to Creative Thought. *Creativity Research Journal*, *22*(2), 219–227. https://doi.org/10.1080/10400419.2010.481539

Gershenson, C. (2008). *Complexity : 5 questions*. [S.l.]: Automatic Press.

Gist, M. E. (1989). The Influence of Training Method on Self-Efficacy and Idea Generation Among Managers. *Personnel Psychology*, *42*(4), 787–805. https://doi.org/10.1111/j.1744-6570.1989.tb00675.x

Glăveanu, V. P. (2014). The psychology of creativity: A critical reading. *The Psychology of Creativity: A Critical Reading. Creativity: Theo-Ries –Research –Applications*, *1*(1), 10–33. https://doi.org/DOI: 10.15290/ctra.2014.01.01.02

Glouberman, S., & Zimmerman, B. (2002). *Complicated and Complex Systems : What Would Successful Reform of Medicare Look Like ? by. Change*. Saskatoon, SK: Commission on the Future of Health Care in Canada. https://doi.org/0-662-32778-0

Goldman, W. (1983). *Adventures in the screen trade: A personal view of Hollywood and screenwriting*. New York: Warner Books.

Gordon, W. J. J. (1961). *Synectics, the development of creative capacity*. New York, NY: Harper.

Gould, S. J., & Eldredge, N. (1977). Punctuated equilibria: the tempo and mode of evolution reconsidered. *Paleobiology*, *3*(02), 115–151.

Grohman, M., Wodniecka, Z., & Klusak, M. (2006). Divergent thinking and evaluation skills: Do they always go together? *Journal of Creative Behavior*, *40*(2), 125–145.

Guilford, J. P. (1950). Creativity. *American Psychologist*, *5*(9), 444–454. https://doi.org/10.1037/h0063487

Guilford, J. P. (1956). The structure of intellect. *Psychological Bulletin*, *53*(4), 267–293. https://doi.org/10.1037/h0040755

Hafting. (2016, November 2). Retrieved November 20, 2016, from http://en.wikipedia.org/wiki/Hafting

Hammer, D., & Elby, A. (2002). On the Form of a Personal Epistemology. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal Epistemology: The Psychology of Beliefs about Knowledge and Knowing* (pp. 169–190). Mahwah, NJ: Erlbaum. Retrieved from http://www2.physics.umd.edu/~redish/788/readings/eresources.pdf

Harrison, G. (1981). Studies of the Myers-Briggs Type Indicator in a personality assessment research institute. In *Fourth National Conference on the Myers-Briggs Type Indicator*. Stanford University.

Heisenberg, W., Eckart, C., & Hoyt, F. C. (1930). *The physical principles of the quantum theory,*. Chicago Ill.: The University of Chicago Press.

Henderson, R. (1995). Of life cycles real and imaginary: The unexpectedly long old age of optical lithography. *Research Policy*, *24*(4), 631.

Hennessey, B. A., & Amabile, T. M. (2010). Creativity. *Annual Review of Psychology*, *61*, 569–598. https://doi.org/10.1146/annurev.psych.093008.100416

Heylighen, Fr. (2008). Complexity: 5 questions. In C. Gershenson (Ed.) (pp. 65–76). [S.l.]: Automatic Press.

History of the concept of creativity. (2016, July 29). Retrieved November 20, 2016, from https://en.wikipedia.org/wiki/History_of_the_concept_of_creativity

Hocevar, D., & Bachelor, P. (1989). A Taxonomy and Critique of Measurements Used in the Study of Creativity. In J. A. Glover, R. R. Ronning, & C. R. Reynolds (Eds.), *Handbook of Creativity* (pp. 53–75). Boston, MA: Springer US. https://doi.org/10.1007/978-1-4757-5356-1_3

Holland, J. H. (2012). Signals and boundaries: Building blocks for complex adaptive systems.

Cambridge, Mass.: MIT Press. Retrieved from http://public.eblib.com/choice/publicfullrecord.aspx?p=3339466

Holland, J. H. (2014). *Complexity: A Very Short Introduction*. Oxford, UK: Oxford University Press.

Huber, J. C. (1998). Invention and Inventivity Is a Random, Poisson Process: A Potential Guide to Analysis of General Creativity. *Creativity Research Journal*, *11*(3), 231–241. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=7421605&site=ehost-live&scope=site

IBM. (2010). IBM 2010 Global CEO Study: Creativity Selected as Most Crucial Factor for Future Success. Retrieved November 11, 2016, from https://www-03.ibm.com/press/us/en/pressrelease/31670.wss

Internet Users by Country (2016). (2016). Retrieved December 17, 2016, from http://www.internetlivestats.com/internet-users-by-country/

Jabar, F. (2014, December 5). Hunting for the Origins of Symbolic Thought. *The New York Times*, pp. 10–13. Retrieved from http://nyti.ms/1z25igk MAGAZINE

Jevons, W. S. (1913). *The Principles of Science: A Treatise on Logic and Scientific Method*. London, UK: Macmillan and Company Limited. Retrieved from https://archive.org/stream/theprinciplesof00jevoiala#page/n7/mode/2up

Kahan, D. (2012). Technology speedup graph. Retrieved December 17, 2016, from http://andrewgelman.com/2012/04/08/technology-speedup-graph/

Karpova, E., Marcketti, S. B., & Barker, J. (2011). The Efficacy of Teaching Creativity: Assessment of Student Creative Thinking Before and After Exercises. *Clothing and Textiles Research Journal*, *29*(1), 52–66. https://doi.org/10.1177/0887302X11400065

Kastelle, T. (2012). Lessons from Kodak's S-curve problems. Retrieved December 18, 2016, from http://timkastelle.org/blog/2012/01/lessons-from-kodaks-s-curve-problems/

Kauffman, S. (2010). Reinventing the Sacred : a New View of Science, Reason, and Religion. New York: Perseus Books Group. Retrieved from http://public.eblib.com/choice/publicfullrecord.aspx?p=479044

Kauffman, S. A. (1995). *At home in the universe: The search for laws of self-organization and complexity*. New York, NY: Oxford University Press.

Kaufman, J. C., & Beghetto, R. A. (2009). Beyond Big and Little: The Four C Model of Creativity. *Review of General Psychology*, *13*(1), 1–12. https://doi.org/http://dx.doi.org.proxy.hil.unb.ca/10.1037/a0013688

Kaufman, J. C., Plucker, J. A., & Baer, J. (2008). *Essentials of Creativity Assessment*. Hoboken, NJ: Wiley.

Keirsey. (2019). What is your temperament. Retrieved March 16, 2019, from https://www.keirsey.com/

Kim, K. H. (2006). Can We Trust Creativity Tests? A Review of the Torrance Tests of Creative Thinking (TTCT). *Creativity Research Journal*, *18*(1), 3–14.

Kim, K. H. (2011). The Creativity Crisis: The Decrease in Creative Thinking Scores on the Torrance Tests of Creative Thinking. *Creativity Research Journal*, *23*(4), 285–295. https://doi.org/10.1080/10400419.2011.627805

Kozbelt, A., Beghetto, R. A., & Runco, M. A. (2010). Theories of creativity. In J. C. Kaufman & R. J. Sternberg (Eds.), *The Cambridge Handbook of Creativity* (pp. 20–47).

Krampen, G. (1997). Promotion of creativity (divergent productions) and convergent productions by systematic-relaxation exercises: empirical evidence from five experimental studies with children, young adults, and elderly. *European Journal of*

Personality, *11*(2), 83–99.

Kuhn, T. S. (1970). *The structure of scientific revolutions* (Vol. Second). Chicago, IL: The University of Chicago Press.

Kurzweil, R. (2005). *The Singularity Is Near: When Humans Transcend Biology*. New York, NY: Penguin Publishing Group. Retrieved from https://books.google.ca/books?id=9FtnppNpsT4C

Larick, R., & Ciochon, R. (1996). African Emergence and Asian Dispersals of Homo. *American Scientist*. Retrieved from http://www.jstor.org/stable/29775783

Lepore, J. (2015). The disruption machine: What the gospel of innovation gets wrong. Retrieved from http://www.newyorker.com/magazine/2014/06/23/the-disruption-machine

Liu, Y. (2008). A new perspective on Darwin's Pangenesis. *Biological Reviews of the Cambridge Philosophical Society*, *83*(2), 141–9. https://doi.org/10.1111/j.1469-185X.2008.00036.x

Lubart, T. I. (2001). Models of the creative process: Past, present and future. *Creativity Research Journal*, *13*(3–4), 295–308. https://doi.org/10.1207/S15326934CRJ1334_07

Martindale, C. (1999). Biological Basis of Creativity. In R. J. Sternberg (Ed.), *Handbook of Creativity* (pp. 137–152). New York, NY: Cambridge University Press.

McNish, J., & Silcoff, S. (2015). *Losing the signal: The spectacular rise and fall of BlackBerry*. Toronto, ON: HarperCollins Canada.

Mednick, S. a. (1962). The associative basis of the creative process. *Psychological Review*, *69*(3), 220–232. https://doi.org/10.1037/h0048850

Meichenbaum, D. (1975). Enhancing Creativity by Modifying What Subjects Say to Themselves. *American Educational Research Journal American Educational Research Journal*, *12*(2), 129–145. Retrieved from http://www.jstor.org/stable/1162416?seq=1#page_scan_tab_contents

Mirror neuron. (2016, October 19). Retrieved November 20, 2016, from https://en.wikipedia.org/wiki/Motor_neuron

Mitchell, M. (2008). Complexity: 5 questions. In C. Gershenson (Ed.) (pp. 95–98). [S.l.]: Automatic Press.

Mitchell, M. (2009). *Complexity: A guided tour*. Oxford, UK: Oxford University Press.

Moore, G. A. (1991). *Crossing the chasm: Marketing and selling disruptive products to mainstream customers*. New York, NY: HarperCollins.

Moore, G. A. (1995). *Inside the tornado: Marketing strategies from Silicon Valley's cutting edge*. New York, NY: HarperCollins.

Moore, G. A. (2002). *Crossing the Chasm: Marketing and Selling Disruptive Products to Mainstream Customers*. New York, NY: HarperCollins.

Moore, G. A. (2014). *Crossing the Chasm: Marketing and Selling Disruptive Products to Mainstream Customers* (3rd ed.). New York, NY: HarperCollins.

Morçöl, G. (2012). *A complexity theory for public policy*. New York, NY: Taylor & Francis.

Morin, E. (2002). The epistemology of complexity. In D. Fried Schnitman & J. Schnitman (Eds.), *New paradigms, culture, and subjectivity* (pp. 325–340). Cresskill, NJ: Hampton Press. Retrieved from http://www.taosinstitute.net/Websites/taos/images/PublicationsWorldShare/New_Paradigms_Culture_and_Subjectivity_4of4.pdf

Moseley, D., Baumfield, V., Elliott, J., Gregson, M., Higgins, S., Miller, J., & Newton, D. (2005). De Bono's lateral and parallel thinking tools. In D. Moseley (Ed.), *Frameworks for thinking: A handbook for teaching and learning* (pp. 133–140). Cambridge, UK: Cambridge University Press. Retrieved from http://public.eblib.com/choice/publicfullrecord.aspx?p=244043

Nader, R. (1965). *Unsafe at any speed : The designed-in dangers of the American automobile*. New York, NY: Grossman.

NASA Science. (2018). Was Galileo Wrong? Retrieved December 15, 2018, from https://science.nasa.gov/science-news/science-at-nasa/2004/06may_lunarranging

NeoLucida. (2015). An authentic, inexpensive, portable camera: Lucida for the 21st century. Retrieved from http://neolucida.com/

Newman, M. (2008). Complexity: 5 questions. In C. Gershenson (Ed.) (pp. 101–104). [S.l.]: Automatic Press.

Newton, D. P., & Donkin, H. (2011). Some notions of artistic creativity amongst history of art students acquired through incidental learning. *International Journal of Education Through Art TA - TT -*, *7*(3), 283–298. https://doi.org/10.1386///eta.7.3.221_2 LK https://unb.on.worldcat.org/oclc/4824598655

Number of Internet Users (2016). (2016). Retrieved December 17, 2016, from http://www.internetlivestats.com/internet-users/

Osborn, A. F. (1963). *Applied imagination : principles and procedures of creative problem-solving.* (3rd ed.). New York, NY: Scribner.

Ostafin, B. D., & Kassman, K. T. (2012). Stepping out of history: Mindfulness improves insight problem solving. *Consciousness & Cognition*, *25*(2), 1031–1036. https://doi.org/10.1016/j.concog.2012.02.014

Pagel, M. D. (2012). *Wired for culture: origins of the human social mind.* New York, NY: W.W. Norton and Company, Inc.

Parkhurst, H. B. (1999). Confusion, lack of consensus, and the definition of creativity as a construct. *The Journal of Creative Behavior.*, *33*(1), 1.

Parkinson, R. (1972). The Dvorak simplified keyboard: Forty years of frustration. *Computers and Automation*, *November*, 18–25. Retrieved from http://infohost.nmt.edu/~shipman/ergo/parkinson.html

Parnes, S. J. (1971). Creativity: Developing Human Potential. *The Journal of Creative Behavior*, *5*(1), 19–36. https://doi.org/10.1002/j.2162-6057.1971.tb00868.x

Phillips, M., & Ferdman, R. A. (2013). A brief, illustrated history of Blockbuster, which is closing the last of its US stores. Retrieved November 11, 2016, from http://qz.com/144372/a-brief-illustrated-history-of-blockbuster-which-is-closing-the-last-of-its-us-stores/

Piketty, T. (2014). *Capital in the twenty-first century*. Boston, MA: Harvard University Press.

Pink, D. H. (2006). *A Whole New Mind: Why Right-Brainers Will Rule the Future*. New York, NY: Penguin Group USA.

Plato. (n.d.). *The Republic*. Retrieved from http://classics.mit.edu/Plato/republic.html

Plsek, P. E. (1997). Working Paper: Models for the Creative Process. Retrieved December 3, 2016, from http://www.directedcreativity.com/pages/WPModels.html

Plucker, J. A., & Beghetto, R. A. (2004). Why Creativity Is Domain General, Why It Looks Domain Specific, and Why the Distinction Does Not Matter.

Plucker, J. A., Beghetto, R. A., & Dow, G. T. (2004). Why isn't creativity more important to educational psychologists? Potentials, pitfalls, and future directions in creativity research. *Educational Psychologist*, *39*(2), 83–96. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=13310450&site=ehost-live&scope=site

Plucker, J. A., & Renzulli, J. S. (1999). Psychometric approaches to the study of human creativity. In R. J. Sternberg (Ed.), *Handbook of Creativity* (pp. 35–61). New York, NY:

Cambridge University Press.

Poincaré, H. (1910). Mathematical creation. *The Monist*, *XX*(3), 321–335. Retrieved from https://ia801609.us.archive.org/3/items/jstor-27900262/27900262.pdf

Popper, K. R., & Bartley, W. W. (1982). *The open universe: An argument for indeterminism*. Totowa, N.J.: Rowman and Littlefield.

Pringle, H. (2013). The origins of creativity. *Scientific American*, *308*(March), 36–43. https://doi.org/doi:10.1038/scientificamerican0313-36

Puccio, G. J., & Cabra, J. F. (2010). Organizational Creativity: A Sytems Approach. In J. C. Kaufman & R. J. Sternberg (Eds.), *The Cambridge Handbook of Creativity* (pp. 145–173). New York, NY: Cambridge University Press.

Puccio, G. J., Firestien, R. L., Coyle, C., & Masucci, C. (2006). A review of the effectiveness of CPS training: A focus on workplace issues. *Creativity and Innovation Management*, *15*(1), 19.

Rantanen, K., & Domb, E. (2008). Simplified TRIZ: New Problem Solving Applications for Engineers and Manufacturing Professionals. New York, NY: Auerbach Publications. Retrieved from http://www.crcnetbase.com/isbn/9781420062731

Restak, R. M. (1984). *The Brain*. Bantam Books.

Reuters. (2018). Global mergers and acquisitions reach record high in first quarter | Reuters. Retrieved March 16, 2019, from https://www.reuters.com/article/us-deals-review/global-mergers-and-acquisitions-reach-record-high-in-first-quarter-idUSKBN1H60EC

Rhodes, M. (1961). An analysis of creativity. *The Phi Delta Kappan*, *42*(7), 305–310. Retrieved from http://www.jstor.org./stable/20342603

Roberts, R. M. (1989). *Serendipity: Accidental Discoveries in Science*. Wiley. Retrieved from https://books.google.ca/books?id=hf57X0s4aPwC

Robilliard, D. (2013). John H. Holland: Signals and boundaries: building blocks for complex adaptive systems : MIT Press, 2012. *Genetic Programming and Evolvable Machines*, *14*(2), 279–280.

Robinson, K. (2011). *Out of Our Minds: Learning to be Creative*. Chichester, UK: Capstone Publishing Ltd.

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). New York, NY: Free Press.

Rogers, E. M., Medina, U. E., Rivera, M. a, & Wiley, C. J. (2005). Complex Adaptive Systems and The Diffusion of Innovations. *The Innovation Journal: The Public Sector Innovation Journal*, *10*(3), 1–26.

Rose, L. H., & Lin, H.-T. (1984). A meta-analysis of long-term creativity training programs. *The Journal of Creative Behavior*, *18*(1), 11–22.

Rosen, R., Rosen, J., Kineman, J. J., & Nadin, M. (2012). *Anticipatory Systems: Philosophical, Mathematical, and Methodological Foundations*. New York, NY: Springer.

Rosenberg, N. (1976). *Perspectives on technology*. Cambridge, UK: Cambridge University Press.

Runco, M. A. (1991). Divergent Thinking. In M. A. Runco & S. R. Pritzker (Eds.), *Encyclopedia of Creativity* (pp. 400–403). Norwood, N.J.: Ablex Pub. Corp.

Runco, M. A. (2011). Divergent Thinking. In M. A. Runco & S. R. Pritzker (Eds.), *Encyclopedia of Creativity* (2nd ed., pp. 400–403). San Diego, CA: Elsevier.

Runco, M. A., & Acar, S. (2012). Divergent Thinking as an Indicator of Creative Potential. *Creativity Research Journal*, *24*(1), 66–75.

Runco, M. A., & Albert, R. S. (1990). *Theories of Creativity*. Newbury Park, CA: SAGE Publications, Inc.

Runco, M. A., & Albert, R. S. (2010). Creativity Research: A Historical View. In J. C.

Kaufman & R. J. Sternberg (Eds.), *The Cambridge Handbook of Creativity* (pp. 3–19). New York, NY: Cambridge University Press.

Runco, M. A., & Chand, I. (1994). Problem Finding, Evaluative Thinking, and Creativity. In M. A. Runco (Ed.), *Problem Finding, Problem Solving, and Creativity* (pp. 40–76). Norwood, NJ: Ablex Publishing Corporation.

Runco, M. A., & Jaeger, G. J. (2012). The standard definition of creativity. *Creativity Research Journal*, *24*(1).

Russ, S. W., & Dillon, J. A. (2011). Associative Theory. In M. A. Runco & S. R. Pritzker (Eds.), *Encyclopedia of Creativity* (2nd ed., pp. 66–71). San Diego, CA: Elsevier, Inc.

Sanders, T. I. (2000). *What is Complexity*. Washington, DC. Retrieved from www.complexsys.org

Sawyer, K. R. (2005). *Social Emergence: Societies as Complex Systems*. New York, NY: Cambridge University Press.

Sawyer, K. R. (2008). *Group genius: The creative power of collaboration*. New York, NY: Basic Books.

Sawyer, K. R. (2012). *Explaining Creativity: The Science of Human Creativity* (2nd ed.). New York, NY: Oxford University Press.

Schawbel, D. (2015). Geoffrey Moore: Why Crossing The Chasm is still relevant - Forbes. Retrieved from http://www.forbes.com/sites/danschawbel/2013/12/17/geoffrey-moore-why-crossing-the-chasm-is-still-relevant/2/

Schonfeld, E. (2011). The rise of the "creative" class. Retrieved November 11, 2016, from https://techcrunch.com/2011/12/14/creative-class/

Schumpeter, J. A. (1950). *Capitalism, socialism, and democracy* (3rd ed.). New York, NY: Harper.

Scott, G., Leritz, L. E., & Mumford, M. D. (2004). The effectiveness of creativity training: A quantitative review. *Creativity Research Journal*, *16*(4), 361–388.

Seelig, T. (2012). *InGenius: A Crash Course on Creativity*. New York, NY: Harper Collins Publishers.

Simon, H. A. (1955). On a Class of Skew Distribution Functions. *Biometrika*, *42*(3/4), 425–440.

Simonton, D. K. (1999a). Creativity as blind variation and selective retention: Is the creative process Darwinian? *Psychological Inquiry*, *10*(3), 309–328. https://doi.org/10.1207/S15327965PLI1004_4

Simonton, D. K. (1999b). *Origins of Genius: Darwinian Perspectives on Creativity*. Cary, NC: Oxford University Press.

Simonton, D. K. (2001). The Psychology of Creativity: A Historical Perspective. Retrieved September 8, 2014, from http://simonton.faculty.ucdavis.edu/wp-content/uploads/sites/243/2015/08/HistoryCreativity.pdf

Simonton, D. K. (2004). Creativity in the Arts and Sciences. In M. C. Horowitz (Ed.), *New Dictionary of the History of Ideas* (Vol. 1, pp. 493–497). New York, NY: Charles Scribners & Sons.

Simonton, D. K. (2007). Rejoinder: Picasso's Guernica creativity as a Darwinian process: Definitions, clarifications, misconceptions, and applications. *Creativity Research Journal*, *19*(4), 381–394. https://doi.org/10.1080/10400410701753341

Simonton, D. K. (2010). Creative thought as blind-variation and selective-retention: Combinatorial models of exceptional creativity. *Physics of Life Reviews*, *7*(2), 190–194. https://doi.org/10.1016/j.plrev.2010.05.004

Simonton, D. K. (2011). Debating the BVSR Theory of Creativity: Comments on Dasgupta (2011) and Gabora (2011). *Creativity Research Journal*, *23*(4).

Sneppen, K., Bak, P., Flyvbjerg, H., & Jensen, M. (1995). Evolution as a self-organized critical phenomenon. *Proceedings of the National Academy of Sciences of the United States of America*, *92*(11), 5209–5213.

Snow, D. C. (2004). Extraordinary efficiency growth in response to new technology entries: The carburetor's "last gasp." *Academy of Management Proceedings*.

Snow, D. C. (2008). Beware of old technologies' last gasps. *Harvard Business Review*, *86*(1), 17–18. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=27996045&site=ehost-live&scope=site

Solé, R. V. (2008). Complexity: 5 questions. In C. Gershenson (Ed.) (pp. 123–126). [S.l.]: Automatic Press.

Solomon, C. M. (1990). What an idea: Creativity training. *Personnel Journal*, *69*(5), 65–71.

Stacey, R. D. (1995). The science of complexity: An alternative perspective for strategic change processes. *Long Range Planning*, *28*(6), 124. https://doi.org/10.1016/0024-6301(95)99970-B

Stacey, R. D. (1996). *Complexity and Creativity in Organizations*. San Fransisco, CA: Berrett-Koehler Publishers, Inc.

Stacey, R. D. (2007). The challenge of human interdependence: Consequences for thinking about the day to day practice of management in organizations. *European Business Review*, *19.4*(4), 292–302. https://doi.org/http://dx.doi.org.ezproxy.une.edu.au/10.1108/09555340710760125

Stacey, R. D., & Griffin, D. (2005). *A Complexity Perspective on Researching Organizations: Taking Experience Seriously*. London, UK: Routledge. Retrieved from http://public.eblib.com/choice/publicfullrecord.aspx?p=256914

Stacey, R. D., & Mowles, C. (2016). *Strategic Management and Organisational Dynamics: The Challenge of Complexity to Ways of Thinking about Organisations* (Seventh). Harlow, UK: Person Education Limited.

Stein, M. I. (1974). *Stimulating Creativity*. New York, NY: Academic Press.

Sternberg, R. J. (2012). The assessment of creativity: An investment-based approach. *Creativity Research Journal*, *24*(1), 3–12. https://doi.org/10.1080/10400419.2012.652925

Sternberg, R. J., & Lubart, T. I. (1991). An investment theory of creativity and its development. *Human Development*. https://doi.org/10.1159/000277029

Sternberg, R. J., & Lubart, T. I. (1995). An investment perspective on creative insight. In R. J. Sternberg & J. E. Davidson (Eds.), *The Nature of Insight* (pp. 535–558). Cambridge, MA: A Bradford Book.

Sternberg, R. J., & Lubart, T. I. (1999). The Concept of Creativity: Prospects and Paradigms. In R. J. Sternberg (Ed.), *Handbook of Creativity* (pp. 3–15). New York, NY: Cambridge University Press.

Suhr, H. C. (2015). Unpacking the Shifting Landscape of Music Evaluation in Indaba Music Contests. In H. C. Suhr (Ed.), *Online Evaluation of Creativity and the Arts* (pp. 129–149). New York, NY: Taylor & Francis.

Takacs, D. (2003). How does your positionality bias your epistemology? *The NEA Higher Education Journal*, (Summer), 27–38. Retrieved from http://www.nea.org/assets/img/PubThoughtAndAction/TAA_03_04.pdf

Tatarkiewicz, W. (2011). *A History of Six Ideas: An Essay in Aesthetics*. Houten, The Netherlands: Springer Netherlands. Retrieved from http://books.google.ca/books?id=1r9ungEACAAJ

Technologies, A. C. (2016). Rabbit Problems in Australia. Retrieved from http://www.animalcontrol.com.au/rabbit.htm

Tenner, E. (1996). *Why things bite back: Technology and the revenge of unintended consequences*. Knopf. Retrieved from https://books.google.ca/books?id=1wUoAQAAMAAJ

Tenner, E. (2011). Unintended consequences: TEDTalk. (TEDTalks, Ed.). Retrieved from http://www.ted.com/talks/edward_tenner_unintended_consequences/transcript?language=en

The CPS Process. (2013). Retrieved November 23, 2013, from http://www.creativeeducationfoundation.org/creative-problem-solving/the-cps-process/

Thompson, B. (2015). What Clayton Christensen got wrong in his theory of low-end disruption. Retrieved from about:reader?url=https://stratechery.com/2013/clayton-christensen-got-wrong/

Thornton, S. (2018). Karl Popper. In *Stanford Encyclopedia of Philosophy*. Stanford University. Retrieved from https://plato.stanford.edu/entries/popper/

Torrance, P. E. (1970). *Encouraging creativity in the classroom*. Dubuque, Iowa: W.C. Brown Co.

Torrance, P. E. (1972a). Can we teach children to think creatively? *The Journal of Creative Behavior*. https://doi.org/10.1002/j.2162-6057.1972.tb00923.x

Torrance, P. E. (1972b). Predictive Validity of the Torrance Tests of Creative Thinking. *The Journal of Creative Behavior*, *6*(4), 236–262. https://doi.org/10.1002/j.2162-6057.1972.tb00936.x

Torrance, P. E., Ball, E. ., & Safter, H. T. (2008). *Torrance tests of creative thinking: Streamlined scoring guide for figural forms A and B*. Bensenville, IL: Scholastic Testing Service.

Toynbee, A. (1962). Neglect of the creative minority. *Sooner Magazine*, (January), 7–9. Retrieved from https://digital.libraries.ou.edu/sooner/articles/p7-

9_1962v34n5_OCR.pdf

Treffinger, D. J., & Ripple, R. E. (1971). Programmed Instruction in Creative Problem Solving. *Educational Leadership*, *28*(6), 667,669-671,673,675. Retrieved from http://www.ascd.org/ASCD/pdf/journals/ed_lead/el_197103_treffinger.pdf

Twitter: number of active users 2010-2016. (2016). Retrieved December 18, 2016, from https://www.statista.com/statistics/282087/number-of-monthly-active-twitter-users/

Vergano, D. (2014). Hot Stew in the Ice Age? Evidence Shows Neanderthals Boiled Food. Retrieved November 20, 2016, from http://news.nationalgeographic.com/news/2014/04/140430-neanderthals-cook-food-evolution-science/

Vincent, J. F. V, Bogatyreva, O. A., Bogatyrev, N. R., Bowyer, A., & Pahl, A.-K. (2006). Biomimetics: its practice and theory. *Journal of the Royal Society, Interface*, *3*(9), 471–482. https://doi.org/10.1098/rsif.2006.0127

Walby, S. (2003). *Complexity Theory, Globalisation and Diversity. Conference of the British Sociological Association*. York, UK. Retrieved from http://www.leeds.ac.uk/sociology/people/swdocs/Complexity Theory realism and path dependency.pdf

Wallas, G. (1926). *The art of thought*. New York: Harcourt, Brace and Company.

Walls, W. D. (2005). Modeling Movie Success When “Nobody Knows Anything”: Conditional Stable-Distribution Analysis Of Film Returns. *Journal of Cultural Economics*, *29*(3), 177–190.

Weisberg, R. W. (2006). *Creativity: Understanding innovation in problem solving, science, invention, and the arts*. Hoboken, NJ: Wiley.

Welsch, P. K. (1980). *The Nurture of Creative Behavior in Educational Environments: A*

Comprehensive Curriculum Approach. Michigan State University.

Wilford, J. N. (2014). Cave Paintings in Indonesia May Be Among the Oldest Known. *The New York Times*. Retrieved from http://www.nytimes.com/2014/10/09/science/ancient-indonesian-find-may-rival-oldest-known-cave-art.html?_r=1

Zimmerman, B. J. (1995). Self-efficacy and educational development. In A. Bandura (Ed.), Self-efficacy in changing societies (pp. 202–231). New York, NY: Cambridge University Press. Retrieved from https://www.researchgate.net/profile/Barry_Zimmerman/publication/247480203_Self-efficacy_and_educational_development/links/549b67770cf2b80371371ad5.pdf

3 Articles

After decades of study, we still don't know much about the creative process (Hennessey & Amabile 2010). The creative process is a complex process. If we accept that as an axiom and begin to study creativity as a complex process, drawing on everything that has been learned from the study of complexity science, we may make more progress in the understanding of creativity. As noted at the end of the literature review of creativity theories, there are no all-encompassing theories of creativity. That is, none address levels from neurons to societies, and everything in between, while offering an explanation of the variations in creative abilities and creative outputs at each level. These articles provide a framework that could form the scaffolding for an all-encompassing theory of creativity and innovation. Viewing the creative process – and the sub-process of the diffusion of innovation – as a complex adaptive process may improve our understanding of the process, and aid in communicating, teaching, and enhancing the creative process. In particular, understanding the diffusion of innovation as a complex system may lead to better predictive analytics, allowing an organization to better understand when to 'let the system run,' when to intervene, and when to abandon a new product launch.

Each of the following articles have established a link between creativity and one characteristic of complex adaptive systems. In *The Order-Chaos Dynamic of Creativity*, the order-chaos characteristic of complex adaptive systems is shown to explain the paradoxes that have been seen in creativity research for many years. *The Complex Adaptive Process of Innovation Diffusion* reveals how real-world diffusion of innovation data supports predictions that arise from viewing the diffusion process as a small-world process, another characteristic of complex adaptive systems. Finally, *The Ontological Emergence of Creativity* reveals how the emergence characteristic of complex adaptive systems can be seen as the same construct as creativity. Together, these three articles present a strong case for recognizing creativity as a characteristic of complex adaptive systems and for continued efforts along this line of research.

3.1 The Order-Chaos Dynamic of Creativity

Abstract

For many years, creativity research had been yielding contradictory results. More recently, these results have come to be regarded as creativity paradoxes. There is a growing body of evidence that highly-creative people tend to operate, either simultaneously or dynamically, at extremes along continuums that are generally considered at odds with one another. More highly-creative people, it seems, tend to find a middle way, not by operating at a mid-point along a continuum, but by operating at and blending two more extreme positions. This is consistent with complexity theory, particularly the *order-chaos dynamic* characteristic of complex adaptive systems. The number of paradoxes discovered in creativity research provides evidence for creativity being a characteristic of complex adaptive systems. This conceptual paper argues that viewing creativity in this way should lead to an enhanced understanding of creativity and innovation, resulting in better creativity enhancement and innovation management approaches and improved tools to identify highly creative individuals.

Keywords: creativity, innovation, complexity science, complex adaptive systems, chaos, order – chaos dynamic.

3.1.1 Introduction

Creativity is almost universally acknowledged as a highly valued ability. For example, a survey of 1,500 CEOs from around the world found that creativity was the number one competency that had to be instilled throughout an organization in order to be successful (IBM, 2010). Csikszentmihalyi (1996) goes so far as to say that the future of the human race is tied to our creativity (p. 6), while Sawyer (2012) asserts that research supports the view that "creativity is a healing, life-affirming activity" (p. 409). Yet, even with the acknowledged importance of creativity, the body of knowledge on the subject is in its infancy. Various creativity researchers have concluded, based on the research to date, that creativity is mysterious, that the results are contradictory, or that the study of creativity contains many paradoxes.

This paper is organized into four sections. The introduction will discuss whether creativity, and the results of creativity research, should be viewed as mysterious, contradictory, or paradoxical, and will introduce the topic of complexity theory. The topic of complexity theory is introduced here so that, while reading section two, the reader may begin to make connections between creativity as *paradoxes* and creativity as an *order – chaos dynamic*; different perspectives of the same phenomena, with the later perspective leading to a new theory of creativity. Section two explores six paradoxes found in the creativity research literature. Section three discusses how a complexity theory of creativity allows us to view the results of creativity research not as mysterious, contradictory, or paradoxical, but as *expected*. Section four includes a conclusion and provides suggestions for future research.

For the purposes of this paper, creativity is defined as follows. A creative product is an idea, product, or process that is new or novel and is appropriate, adaptive, or of value, in the context in which it was derived. A creative person is someone who conceives of creative products. However, it should be kept in mind that every second of every day is unique. Each moment is new, we have never encountered it before. Dealing with and responding to each moment is an exercise in creativity. Not only were we born creative, but we also would not survive with a total lack of creativity. Creativity exists on a continuum. When we refer to something as creative, what we really mean is that it is highly creative, or more creative than average.

3.1.1.1 Mysterious, Contradictory, or Paradoxical?

Some researchers have concluded that creativity works in *mysterious ways*. For example, Boden (2013) concludes that creativity is, from the neuroscientific perspective, a mystery. She points out that while neuroscience is able to shed some light on associative pathways, being able to explain relevance is another matter. In theory, any concept could be related to any other, but how we sort through the near-infinite number of associations to arrive at those that are worthy of some consideration is an area where neuroscience has not been able to offer even a hint of an answer. In *Creativity is a Mystery*, Ford (1995) states that "researchers and practitioners are both generally frustrated by the state of our understanding of creativity" (p. 13). He blames this on the lack of a unifying theory, saying "my head is littered with potentially useful clues, but I can't formulate a theory that puts the pieces together" (p, 13).

Decades of creativity research has yielded results that are full of contradictions. For example, Csikszentmihalyi (1996) notes ten seemingly contradictory characteristics of the highly creative person's personality: lots of physical energy – but often desires or requires rest and quiet; smart – naïve; disciplined – playful, or responsible – irresponsible; rooted in reality – flights of imagination and fantasy; extroversion – introversion; proud – humble;

masculine – feminine (at times resulting in androgyny; in psychological, not sexual, terms); traditional and conservative – rebellious and iconoclastic; objective – passionate; suffering – enjoyment (pp. 58-76). In a review of the creativity literature, Tardif and Sternberg (1988) suggest there are "major controversies and contradictions" in discussions of personality characteristics associated with highly creative persons and in the creative process. They note only one underlying theme: "the creative individual as one in conflict" (p. 437). Among others, they identified a conflict between: criticism and confidence; the tendency to be socially withdrawn and socially integrated; and the creative process takes time, but often includes flashes of insight. Amabile (1996) has said that "creativity researchers are often accused of not knowing what they are talking about" (p. 19). While she said this in relation to the criterion problem (that is, creativity research lacks objective criteria for novelty, appropriateness, and value – or whatever other criteria may be used in the definition of creativity), it could apply equally well to the contradictions that Amabile goes on to discuss in creativity research findings. For example, contradictory results have been found in the effect of: stimulus prior to task engagement, social reinforcements, external evaluation, and competition, on creative outcomes.

Contradictory research results have led others to conclude that there are many paradoxes associated with creativity (see, for example, Bassett-Jones, 2005; Kaufman & Gregoire, 2015). Section two of this paper will take a more detailed look at several paradoxes identified by creativity researchers.

Mysterious, contradictory, or paradoxical – which, if any, is it? The question is more clearly answered by breaking it into three questions: Is creativity mysterious? Are the results of creativity research contradictory? Is creativity paradoxical? Simply put, the answers are: yes, yes, and yes.

The answer to the first question is made clear by considering a widely accepted definition of the word mysterious: "difficult or impossible to understand, explain, or identify" (Oxford Dictionaries, 2018b). This is the reason we do research. While creativity may be difficult to understand and explain, research continues so that we might further our understanding of the subject and make it less difficult to understand and explain. So, yes, creativity is mysterious, in that it is difficult to understand and explain, but it is hoped that research will make creativity less mysterious – much to the chagrin of some who appreciate the mysterious nature of creativity. There are also those who argue that a complete understanding of the creative process would mean there is no creativity left – since anyone could apply 'the process' and derive the same outcome (Briskman, 1980). This paper will shed some light on why we should be able to formulate a much better understanding of creativity, while never being able to completely remove the mystery.

Are the results of creativity research contradictory? Many researchers have commented on the contradictions revealed by creativity research. As far back as 1963, Frank Barron (1963) wrote that "the creative genius may be both more primitive and more cultured, more destructive and more constructive, occasionally crazier and yet adamantly saner, than the average person" (p. 224). Rothenberg (Rothenberg & Hausman, 1976), has written extensively about Janusian thinking and its constructive roll in the creative process. Janusian thinking is "the capacity to conceive and utilize two or more opposite or contradictory ideas, concepts, or images simultaneously" (Rothenberg, 1971, p. 195). In *Creativity in Context* (Amabile, 1996) attempts to explain away many of the contradictions found in the body of creativity research literature, as does Sternberg (1999) in the *Handbook of Creativity*. Livingstone, Palich, and Carini (2002) take a different approach to these contradictions. They suggest that we need to embrace "paradox and contradiction as the very vehicles through which positive change and growth in the organization occur" (p. 322). Whereas, Welling (2007) argues that the contradictions seen in creativity research arise because "high creativity is often not the result of a single operation, but results from a longer period in which several operations are put to use during the discovery process" (p. 173), while less creative efforts are characterized by less complex cognitive operations applied over a shorter time frame. Mihaly Csikszentmihalyi (2009), has suggested that "each of us is born with two contradictory sets of instructions" (p. 11), one that supports creativity and one that works against it, while Carl Jung has emphasized the importance of contradictions in all psychological aspects of life (Jung, Fordham, & Adler, 1953).

Is creativity paradoxical? Rather than focusing on the *contradictions* found in the results of creativity research, Kaufman and Gregoire (2015) consider the *paradoxes* evident in creative people and the creative process. To fully understand this different perspective, some definitions may be helpful. A contradiction is "a combination of statements, ideas, or features which are opposed to one another" (Oxford Dictionaries, 2018a), while a paradox is "a seemingly absurd or contradictory statement or proposition which when investigated may prove to be well founded or true" (Oxford Dictionaries, 2018c). Decades of contradictory research findings are giving way to the understanding that creativity is full of paradoxes. That is, the contradictory creativity research findings are not suggestive of actual contradictions that need explanations related to the flaws of one study or the shortcomings of the theory being applied. Instead, it is becoming apparent that many of these seemingly contradictory results are correct and creativity is, indeed, full of paradoxes.

The paradoxes of creativity will be explored in more detail in section two. However, if it is true that the creative process and the creative person are full of paradoxes, then there is a need for a new theory of creativity that accounts for this. A review of the literature reveals that none of the current theories of creativity account for or explain the many paradoxes (Lambert, 2017; Runco, 2014; Runco & Albert, 1990; Sternberg, 1988). A review of *Wired to Create* (S. B. Kaufman & Gregoire, 2015), which provides a good synopsis and overview of the state of creativity research, reveals several areas of creativity-related paradoxes. Not only do they identify several paradoxes, but they also suggest that creative people move dynamically along the continuums implied by those paradoxes.

3.1.1.2 Complex Adaptive Systems

It is a premise of this paper that our understanding of creativity is in its infancy because there is not yet an adequate, over-arching and unifying theory of creativity that is consistent with the majority of the research findings. This paper has taken the first step toward a comprehensive, complexity-science-based theory of creativity; a *complexity theory of creativity*. In a complexity theory, creativity is an expected outcome of all complex adaptive systems.

This paper is not the first to suggest that there is a link between creativity and complexity. Csikszentmihalyi wrote that if he had to sum up in one word what made the personality of highly creative people different, it would be *complexity*. However, by this, Csikszentmihalyi meant that the personality of the highly creative person contained contradictory extremes "at the same time, or a different times, depending on the situation" (Csikszentmihalyi, 1996, p. 57). Past work that attempted to understand creativity by viewing it through the lens of complexity theory has been limited in at least one of five ways. They: 1) were based on early efforts at conceptualizing a theory of complexity, frequently referred to as chaos theory at the time (see, for example, Csikszentmihalyi, 1996; Richards, 2001; Stacey, 1996); 2) were limited in their scope of application. For example, Stacey's (1996) framework related only to organizations or people and groups operating within an organizational context; 3) have been limited in the scope of the characteristics of complex systems that they dealt with. For example Sawyer (1999) only attempts to relate creativity to emergence; 4) use a domain-specific, bottom-up approach, which is not conducive to the development of a broadly applicable theory (see, for example, Arecchi, 2007; who looks at the linkages between creativity and complexity from an information theory perspective); 5) point out analogies between complexity theory and creativity, rather than seeing creativity as the result of a complex adaptive system (for example: Richards, 2001).

The contribution of this paper is to situate the paradoxes, identified through years of creativity research, within modern complexity theory. Specifically, viewing them from the perspective of an order-chaos dynamic, one of the notable characteristics of complex adaptive systems. This is part of a larger effort to develop a broad, over-arching theory of creativity based on creativity as an *emergent* characteristic of complex adaptive systems.

Scott Kaufman notes that "almost by definition, creativity is complex" (S. B. Kaufman, 2013). But, is creativity the result of a complex adaptive system? This paper proposes that, similarly, almost by definition, complex adaptive systems are creative systems, as should become evident in the following pages.

3.1.1.2.1 Primary Characteristics of Complex Adaptive Systems

Complexity is challenging to fully understand. However, the challenge can be reduced by focusing in on one type of complexity, and then understanding its primary characteristics. Holland (2014), highlights the difference between complex physical systems and complex adaptive systems. He describes complex physical systems as "arrays of elements, in which interactions typically depend only on effects propagated from nearest neighbours" (p. 6), while complex adaptive systems consist of elements – usually called agents – that learn or adapt as they interact with other agents and their environment. The range of interactions – breadth and depth – and adaptation are the key differentiators between complex physical systems and complex adaptive systems.

This paper is concerned with complex adaptive systems. A complex adaptive system is one in which a number of diverse, interconnected, interdependent elements, referred to as agents, adapt their behaviour based on interactions with other agents and their environment. Complex adaptive systems include the human brain, all living organisms, economies, stock markets, and colonies of social insects.

These complex adaptive systems result in unpredictable outcomes and emergence (Robilliard, 2013). While the outcomes may be unpredictable, they often follow predictable patterns. For example, ant colonies follow an exploitation-exploration dynamic when it comes to foraging. There is a predictable pattern seen in how ant colonies find and utilize sources of food. When a new food source is being exploited, a small number of ants explore for new food sources. As the existing food source dwindles, more ants move from exploiting to exploring. While this pattern is quite predictable, the exact number of ants, or the ratio of ants dedicated to each task at any moment, cannot be predicted.

While there are many different theories of complexity (see, for example, Arthur, 2009; Bak, 1996; Holland, 2012; Kauffman, 1995; Stacey, 1996), there are some characteristics of complex systems that are common to most, or all, of these theories. They include the following.

Emergence is the appearance of a new, novel characteristic[35] of the system as a whole that could not have been predicted by studying the properties of the individual elements and their interactions. Agents self-organize, with low-level rules giving rise to unforeseen properties and behaviours at the higher, system level. Examples include human societies, life, consciousness, cities, the stock market, and the intelligent behaviour of ant colonies. In these systems, the agents influence the higher-level system, and the system influences the agents. Emergence can also take place over multiple levels. For example, macromolecules such as proteins emerge from the interaction of molecules; macromolecules form cells, cells form tissue, tissues form organs and organ systems, organs form organisms, organisms form populations, populations form communities, social systems and ecosystems, and ecosystems form biospheres (Lobo, 2008). In these systems, individual agents affect the higher level emergent, and the emergent effects the lower level agents. "A very small change in a single macromolecule can have a profound effect on an organism, or even a population, when magnified through levels of complexity" (Lobo, 2008, para. 7). This paper is grounded in the hypothesis that creativity is an emergent property of all complex adaptive systems. The emergent characteristics of a complex adaptive system are new, novel, unexpected, and adaptive. Therefore, complex adaptive systems meet the definition of creative systems and the emergent characteristics are creative outputs (Lambert, 2018).

Complex systems result in inverse power law distributions, giving rise to what is called **fat-tailed behaviour**. Inverse power law distributions consist of a great many occurrences of insignificantly small events and fewer and fewer occurrences of larger and

[35] The characteristic may be a structure, pattern, behaviour, or process, and may be referred to as the emergent.

larger events. As a result, in complex systems, there is a greater likelihood of extreme events than there is in a system that exhibits a Gaussian (normal) distribution. Earthquakes and landslides follow an inverse power law (Bak, 1996), meaning there is always a chance for an earthquake or landslide larger than any previously recorded. When it comes to creativity, movie industry box office receipts have been shown to follow an inverse power law (Walls, 2005). Social media shares, the selling price of artworks, and the size of crowd-funding campaigns also likely follow an inverse power law. In inverse power law distributions, the average and standard deviation become meaningless (Bak, 1996). In any sample, the average grows larger as the sample size increases, while the standard deviation approaches infinity.

Self-organized criticality: Consider the creation of a sand pile by dropping one grain of sand at a time, from the same location, onto a flat surface. Eventually the grains of sand form a pile and eventually, the sand pile reaches a critical state, referred to as self-organized criticality – a state where the next grain of sand produces a disturbance in the sandpile when it lands, resulting in an avalanche. This avalanche may be large or small. If this process is continued, it will be seen that there are many small landslides and fewer larger ones. The distribution of landslides is an inverse power law. Self-organized criticality also exists in social systems. For example, Tadić, Dankulov, and Melnik (2017) show how the phenomenon is seen in knowledge creation while Zhukov, Kanishchev, and Lyamin (2016) investigated self-organized criticality in market price dynamics as well as birth and death rate dynamics. It could also be argued that self-organized criticality is present in social networks, in a way that applies to the diffusion of innovation.[36]

Sensitive dependence on initial conditions is related to self-organized criticality. Consider a sand pile that has reached a state of self-organized criticality. The size of the next avalanche is dependent on the orientation of every grain of sand and its relationship to all the grains around it. A minor reorientation of one grain of sand could radically change the result of the next grain of sand dropped. Social networks are dependent on the relationships between people and their environments as well as the information flow throughout the network. A small change anywhere in the system can be amplified through positive feedback loops.

Patterns are expected, but specific events cannot be predicted: It can be predicted that a complex adaptive system will result in creative output, but the specific form of that creative output cannot be predicted. Also, it can be predicted that a complex adaptive system will result in outputs that follow an inverse power law, but the exact form of the power law and which items result in the largest impact cannot be predicted. For example, complex adaptive systems theory, when applied to creativity and innovation, predicts that the popularity (or value) of creative outputs in any category will follow an inverse power law, but the exact shape of that power law, and which product falls where on the distribution, cannot be predicted.

---

[36] That is, each potential adopter has a different level of desire to adopt and a different level of resistance to adoption. Resistance to adoption being a composite of the Roger's (2003) five characteristics of innovations that explain differences in rates of adoption: relative advantage, compatibility, complexity, triability, and observability.

Self-similarity is the property of an object being the same, or similar to, a part of itself (the whole has the same shape or configuration as one or more of its parts) or an object of the same categorization. There is also self-similarity between complex adaptive systems. The behaviour of one complex adaptive system is similar to the behaviour of other complex adaptive systems.

Order – chaos dynamic: all life exists between the extremes of complete order and complete chaos, with dynamic forces pulling it in opposite directions (S. A. Kauffman, 1995). This Order – Chaos Dynamic (OCD) is a signature of complex adaptive systems. The many characteristics of a complex adaptive system can be expected to be continuums along which the system will move as it adapts to its environment. The OCD characteristic appears to be the result of the same underlying principles that drive the exploitation – exploration search-dynamic of foraging ants.

3.1.2 Creativity: Paradoxes or Dynamic Continuums?

As discussed previously, the results of creativity research could lead us to view creativity as mysterious, as full of contradictions, or as full of paradoxes. Alternatively, the results of creativity research could be seen as being expected, given the OCD characteristic of complex adaptive systems. This section will illustrate that the results are consistent with a complexity theory of creativity.

3.1.2.1 Knowledge – Naivety Continuum

Some domain knowledge is necessary for creativity (Amabile, 1996; Weisberg, 1999) and increasing knowledge leads to increasing levels of creativity, to a point. Too much domain knowledge is thought to inhibit flexible thinking, thereby reducing creativity. This results in knowledge having an inverted, U-shaped relationship with creativity. That is, creativity is low with low levels of domain-specific knowledge, increases to a maximum as knowledge is increased, then drops off as knowledge increases further. A larger knowledge base creates more opportunities for making associations. On the other hand, experts tend to fall back on their existing knowledge, rather than searching for a more creative solution (S. B. Kaufman & Gregoire, 2015). The most convincing research supporting this inverted U-shape relationship between knowledge and creativity comes from Simonton (1983). Simonton found that creativity increases with higher levels of formal education, up to a maximum, and then decreases with further levels of education. The data indicates that in the early 20th century, the highest levels of creativity were reached around the second year of post-secondary education. Reaching the highest levels of creativity now takes until the middle of graduate studies (Sawyer, 2012), presumably because of an increasing knowledge base and complexity in most fields. Simonton surmises that the drop in creativity may be a result of highly educated persons developing an over-commitment to traditional perspectives in their field (Simonton, 1983). Certainly, it does seem that while a PhD student is expected to search out alternative views or explanations for their results and explore the arguments against their thesis, they must also be ready to vigorously defend their thesis. This could lead to some of those with advanced degrees being conditioned to argue against alternatives views that are at odds with the currently accepted view.

Intelligence also has an interesting relationship with creativity. In the early days of psychological research, creativity was not studied as its own subject area because it was thought to be something that came along with high intelligence (Sawyer, 2012). In the 1920s Lewis Terman (Terman, 1925) began a longitudinal study of high-IQ children (140 and above). These intellectually gifted children were followed for decades by Terman and his successors. This study revealed that while IQ is a good predictor of academic success, it is of questionable value as a predictor of creative accomplishment. While the intellectually gifted group did have a higher degree of creative accomplishment than their lower-scoring counterparts, within the gifted group, higher IQ did not predict higher accomplishment (Sawyer, 2012; Simonton, 1999). Further research (Getzels & Jackson, 1962; Fuchs-Beauchamp, Karnes, & Johnson, 2016), has expanded on Terman's work and given rise to what is now known as the threshold theory. The threshold theory claims that IQ and creativity are correlated up to an IQ of approximately 120, beyond which there is no relationship between the two (Fink & Neubauer, 2006), suggesting that intelligence is a necessary, but not sufficient, precursor to creativity (Benedek, Jauk, Sommer, Arendasy, & Neubauer, 2014). That is, low intelligence generally results in low creativity, while moderate intelligence generally results in moderate creativity, but the creativity of a highly intelligent individual cannot be predicted.

While there is a great deal of contradictory research in these relationships, it does seem clear that the relationship creativity has with knowledge and intelligence is not linear. Those with the highest levels of knowledge or intelligence may not be those with the highest levels of creativity. But what about a dynamic relationship?

Martindale (1999) has shown that highly creative people exhibit lower levels of cortical activation when performing creative tasks (multiple uses test, for example, how many uses can you think of for a brick) than when performing tasks that require less creativity (a standard intelligence test). This difference in cortical activation is not seen in less creative people. Thus, creativity is associated with high variability in cortical activation. Research has also shown that highly creative individuals have lower cortical activation while performing a creative task than their baseline level (Martindale & Armstrong, 1974). Martindale associates this decreased cortical activation with the defocused attention often found with good performance in divergent thinking tasks, his theory is that highly creative people are selective with the speed at which they process information (Kaufman & Plucker, 2011, p. 774).

This variability in cortical activation can be interpreted as an effective variability in intelligence. While the creative person's intellectual ability is not changing, his or her level of focused attention is. A high level of focused attention is required to perform well on an intelligence test, as it affects cognitive processing speed, while a low level of focused attention is required to perform well on a multiple uses test.[37] The highly creative person is effectively varying how much or how little they utilize their intelligence, as defined by an IQ test, by allowing slower processing and unfocused attention.

The same argument applies to knowledge. Particularly when education is used as a proxy for knowledge, as is the case in Simonton's work. Here it is expected that defocused attention – low cortical activation – may make use of low-level knowledge, or routinized knowledge, while avoiding the higher-level knowledge that requires focused attention. In this context, low-level knowledge means specific and concrete, while high-level means more abstract, conceptual knowledge – the knowledge that is more likely to be accumulated in higher levels of education.

This knowledge – naivety continuum is the same as, or very similar to, the expert-novice continuum. An expert has access to a great deal of knowledge, but when the expert

[37] Note that Martindale also included a remote associates test, which requires a mix of creativity and intelligence, and found that highly creative people showed a degree of cortical activation higher than when working on a multiple uses test and lower than when working on an intelligence test.

becomes too indoctrinated in their field, he or she may become stuck in routinized thought patterns, rather than allowing for new connections between bits of knowledge, the way a novice might.

In summary, the highly creative person seems to be able to make use of their knowledge, intelligence and expertise when it is most beneficial (when convergent thinking is required for effective creative problem solving), but also ignore it, to greater or lesser degrees, when that is more beneficial (when divergent thinking is required for effective creative problem solving).

3.1.2.2 Psychological Health – Psychiatric Disorders Continuum

The link between creativity and psychosis has been of interest since the earliest creativity studies (Eysenck, 1993), extending as far back as the days when Aristotle claimed that "no great genius has ever existed without a strain of madness" (Kyaga et al., 2011, p. 373). In recent years, research has begun to reveal some clues about the long-recognized connection between the two.

Kyaga, et al. (2011), studied the records of 300,000 Swedish individuals who had received in-patient treatment for schizophrenia, bipolar disorder or unipolar depression, and their relatives, and compared them with a control group. They found that those with bipolar disorder and, to a lessor degree, those with schizophrenia were over-represented in creative professions. Those with unipolar depression showed no difference compared to the overall population. Relatives of both schizophrenics and those with bipolar disorder were over-represented in artistic and scientific occupations. Relatives of those with bipolar disorder showed greater over-representation in scientific occupations, while relatives of individuals with schizophrenia had greater over-representation in artistic occupations.

Eysenck (1993,1995, 2003) explains the relationship between mental illness and creativity using his three-factor model of personality traits. Eysenck has attempted to show a biological basis for three personality traits: extraversion, neuroticism, and psychoticism. For the purposes of this discussion, psychoticism is the trait of interest. Psychoticism is defined as a trait which predisposes people towards psychosis. That is, low psychoticism scores indicate the low likelihood of developing psychosis or psychotic episodes, while higher psychoticism scores are indicative of a higher probability of developing psychosis or psychotic episodes.

Schizophrenics, those with bipolar disorder, and highly creative people not suffering from a mental disorder tend to score high on tests of psychoticism (Eysenck, 1995), in the unusualness of their choices in object sorting tests (Dykes & McGhie, 1976), and in the remoteness of their responses in word association tests (Martindale, 1999). The hypothesis is that psychotics and highly creative people not suffering from a mental disorder use the same, or a similar, *overinclusive* cognitive approach (Eysenck, 1993). "Cognitive overinclusiveness is the tendency to consider a broad range of associations as possibly relevant to a problem and which allows for the production of creative ideas" (Fasko, 2011, p. 137). Highly creative people not suffering from a mental disorder also score high on other personality traits – ego-strength, for example – that are thought to keep them from suffering psychosis, or at least provide the resources necessary to deal "with psychological difficulty and perhaps even to harness and guide it toward purposeful ends" (Barron, 1988, Fodor, 1995, p. 636). In a study of college students, Fodor (1995) found that psychosis-prone individuals (those with high psychoticism scores), who also scored high in ego-strength, exhibited the greatest creativity compared to three other categories of students: psychosis-prone with low ego-strength, not psychosis-prone with high ego-strength, and not psychosis-prone with low ego-strength. If overinclusive thinking is what gives psychotics and highly creative people who are not suffering from a mental disorder access to unusual ideas, ego-strength may be the mediating factor that helps highly creative people not suffering from a mental disorder keep their ideas grounded in reality. Viewed in this way, overinclusiveness is seen to be associated with divergent thinking and novelty, while ego-strength may be associated with convergence and value/usefulness/applicability.[38]

Eysenck (1993) relates overinclusiveness to relevance. That is, the overinclusive individual will entertain possible solutions to a problem that others would deem irrelevant, giving the creative individual access to a broader set of ideas, or combination of ideas, with which to come up with a creative solution. The psychotic person is unable to judge what is truly irrelevant, while the ego strength of the highly creative person who does not suffer from a mental disorder is able to discover remote, yet rational links between ideas. This understanding of overinclusiveness is directly related to the range of associations that an individual makes. Therefore, a measure of the *associative gradient* popularized by Mednick (1962) may double as a measure of overinclusiveness and psychoticism. Mednick's associative gradient has been referred to as an *associative horizon* by Eysenck (1993) and as an associative hierarchy by Martindale (1999). Martindale further points out that a flat associative hierarchy is the same phenomenon as defocused attention.

Associative gradients: We can view all mental elements as being related to each other in some way. Some combinations are closely associated, others are remotely associated and may require multiple steps of associative linking. Mednick describes the person who is more

[38] Three terms often used in the second half of a definition of creativity: novel and useful, applicable, or of value.

likely to come up with a remote association as having a relatively flat associative gradient. In a word association test, people with a steep associative gradient will quickly generate a short list of closely associated words (for example, tree – leaf), but they will also quickly exhaust the associations that they have access to. Those with flat associative hierarchies will typically generate associations more slowly, beginning with closely associated words, but they will not quickly exhaust their supply and will instead continue on with more and more remotely associated pairings (Mednick, 1962).

It is hypothesized that while the highly creative individual makes constructive use of overinclusiveness, which provides him or her with a flat associative hierarchy, the psychotic personality is lacking the necessary control to maintain relevance and constructive thought. What allows one person who scores high on psychoticism to be creative while another is psychotic? It may be that while the highly creative individual has a fairly permeable *filter*, allowing many possible solutions to be considered, the psychotic has a "defective filter" (Cromwell, 1968), allowing the truly irrelevant to be woven into narratives that make no sense to others. Eysenck (2003) suggests that it may have to do with the amount of stress experienced, a difference in dopamine activity, or the presence of positive factors such as high ego-strength. That is, the highly creative person has an additional trait that allows high psychoticism to manifest as creativity rather than psychosis.

Frank Barron (1953) developed the ego-strength scale as a measure to predict response to psychotherapy but found it to have broader applicability as an assessment of adaptability and personal resourcefulness. Those who score high on the ego-strength scale are thought to "lack chronic psychopathology, be alert, persistent, self-confident, intelligent and resourceful, [have] excellent reality testing, good interpersonal coping skills, strongly developed interests, [while being] somewhat rebellious, competitive, and cynical" ("mmpi-info | Supplementary Scales," 2011).

Many of the traits discussed have been found to be heritable, but the research yields contradictory results (Martindale, 1999). Bouchard, Lykken, Tellegen, Blacker, and Waller (1993), have suggested that *emergenesis* may explain the contradictory results in the heritability of creativity research. Emergenesis the term given to a higher order trait – such as creativity - that only emerges if all the other required traits (for example, intelligence, psychoticism, and perseverance) are also present. In this way, creativity can be heritable, without running in families.

In summary, overinclusiveness results in a wide associative horizon and high psychoticism scores for highly creative individuals and psychotics. Highly creative individuals benefit from the balancing effect of ego-strength and, perhaps, lower stress, thereby turning overinclusiveness into a net benefit, rather than a net negative.

Perhaps the highly creative person is performing a dynamic dance, allowing ego-strength to subside long enough for him or her to dip a toe in the waters of psychotic overinclusiveness, after which ego-strength is redeployed to pull back from psychopathology, while armed with associations that other people not suffering from a mental disorder would never have access to. While this may be mere speculation at this time, the preponderance of anecdotes in this area are not at odds with this explanation, and the explanation fits well with other dynamic-continua examples discussed in this paper.

3.1.2.3 Mindfulness – Mind-Wandering Continuum

The previous discussion about highly creative people dynamically varying their level of focused attention is directly related to the mindfulness – mind-wandering continuum. In this context, mind-wandering is synonymous with the terms daydreaming, and defocused attention. Mindfulness is nonjudgmental awareness and focus on the present moment, which is largely an external focus. This is at odds with the internal, unfocused nature of daydreaming, or mind-wandering.

Zedelius and Schooler (2015), point out that mindfulness and mind wandering are viewed as opposing constructs, yet research has shown that each can have a positive effect on creative performance. Their hypothesis, for which they provide some evidence, is that mind-wandering is a useful approach when unconscious associative processes are used to solve problems through the application of an insight approach. On the other hand, mindfulness is useful when taking the analytic path to problem-solving.

Unfortunately, the problems used in most creativity research are unidimensional in this sense. That is, they are best solved by either insight or analysis. Real life problem solving generally requires both: insight and analysis, divergent thinking and convergent thinking. It can, therefore, be expected that highly creative people will be good at both. That they will dynamically switch back and forth between an insight approach and analysis; between divergent thinking and convergent thinking; between mind wandering and mindfulness; and between an internal focus (or lack of focus) and an external focus.

Psychologists Schooler, et al. (2014), advocate for an approach using a middle-way. They suggest finding a balance between mindfulness and mind wandering to mitigate some of the mind wandering's "more disruptive consequences" while keeping some of its unique benefits. Given the varying requirements of creative problem solving (which can be summarized, or at least well represented, by the convergent-divergent thinking continuum) it seems likely that dynamically shifting between mindfulness and mind wandering would provide a more optimal creative problem-solving strategy than trying to find and maintain an 'optimal' mid-point.

3.1.2.4 Executive Attention Network – Default Network Continuum

The mindfulness – mind-wandering continuum discussed in the previous section is very closely related to several other continua identified in Kaufman and Gregoire's (2015) *Wired to Create*, including; outward – inward focus; deliberate – spontaneous; work – play; focused effort – inspiration; reality – imagination; action – reflection; rational – intuitive thought; cognitive – emotional approach. All of these share a relationship with the executive attention network – default network continuum, and duel process theory. In fact, most of these continua are either synonymous, or different perspectives of the same phenomena.

The default network, which Kaufman and Gregoire refer to as the imagination network, is an interconnected system of brain regions that is active when an individual is not focused on the external environment. It is active when individuals are "engaged in internally focused tasks including autobiographical memory retrieval, envisioning the future, and conceiving the perspectives of others" (Buckner, Andrews-Hanna, & Schacter, 2008), that is, self-reflection, imagination, and empathy. As the name implies, the default network is thought to be the network of brain regions that are active while our attention is unfocused, or inward focused, which is the essence of daydreaming and mind wandering. The executive attention network is an interconnected system of brain regions that are active when our attention is externally focused. Highly focused attention tends to be more externally focused, but of course, there is a continuum between the two: focused and defocused, internal and external (Bendetowicz et al., 2018).

Schooler, et al. (2014) note that "a balance between external directed focus and free-flowing inward attention may be our natural state." However, that balance must be a dynamic one, since it seems unlikely one could find and maintain a steady-state mix of the two. Kaufman and Gregoire (2015) summarize this dynamic by concluding that "creative people are particularly good at exercising flexibility in activating and deactivating these brain networks that in most people tend to be at odds with each other. In doing so, they're able to juggle seemingly contradictory modes of thought – cognitive and emotional, deliberate and spontaneous" (2015, p. xxix).

Dual process theory postulates that there are two different pathways that we use to process information. The *system one pathway* is fast, involuntary, and unconscious, relying on previously established patterns. It lacks details and context, and it is heavily influenced by established stereotypes and our existing belief system. Our *system two pathway* is slow, deliberate and conscious. The information processed is more explicit and detailed ("Dual Process Theory definition | Psychology Glossary | alleydog.com," 2018). From this description, it is apparent that system-one information processing is related to mindless, mind wandering, or defocused cognition, while system two information processing is engaged in mindful, focused cognition.

There is also evidence of a third network, called the salience network (Seeley et al., 2007). It is thought that while the default network generates ideas, the salience network determines which ones get passed on to the executive attention network (Brenner, 2018). The salience network appears to be the filter. A filter that is more easily dynamically adjusted by highly creative people in order to move along a continuum, giving more emphasis to the default network, and allowing more remote ideas to pass through when divergent thinking is required, and attenuating the 'noise' when convergent thinking is required.

Beaty, Benedek, Silvia and Schacter (2016) have outlined how functional Magnetic Resonance Imaging (fMRI) studies have revealed that creative thought involves dynamic interactions of various large areas of the brain. In particular, they noted cooperation between the executive attention network and the default network – two areas that usually "show an antagonistic relation" (p. 87). They point out that this cooperation during creative tasks is consistent across domain-general divergent thinking tasks and in the domain-specific creative areas of poetry, music and visual art. They "contend that the default network influences the generation of candidate ideas, but that the control network can constrain and direct this process to meet task-specific goals via top-down monitoring and executive control" (p. 92). That is, creativity requires a dynamic balance between the executive attention network and the default network.

3.1.2.5 Convergent – Divergent-Thinking Continuum

Guilford's (1967) structure of intellect theory identifies 120 different intellectual abilities[39]. However, at a higher level, all intellectual functioning can be seen as operating in one of two modes: convergent thinking, or divergent thinking. Convergent thinking "tends toward retaining the known, learning the predetermined, and conserving what is" while divergent thinking "tends toward revising the known, exploring the undetermined, and constructing what might be" (Getzels & Jackson, 1962, pp. 13-14). Carson (2010), describes divergent thinking as "the propensity to generate multiple solutions to a single [ill-structured] problem or dilemma" (p. 126) and convergent thinking as "the type of thinking you do when

[39] Later modified to include 150.

you access the contents stored in your brain (including knowledge and memories) to come up with the one correct answer to a well-defined problem" (p. 125).

A typical intelligence test – which yields an Intelligence Quotient (IQ) – measures convergent thinking, while the Torrance Test of Creative Thinking (TTTC), is the most commonly used test of divergent thinking. However, creative thinking requires both convergent and divergent thinking (Runco, 2014).

Convergent and divergent thinking are generally seen as very different types of thinking processes. People are often better at one than the other. Since creativity requires both convergent and divergent thinking, many highly creative people are good at both. Kaufman and Gregoire (2015), note that highly creative people fluidly and flexible switch between thinking modes, depending on changing circumstances and the requirements of the moment. They also point out that research has revealed that creative people "engage in rapid switching of thought processes and exhibit nearly simultaneous coexistence between a number of these processes" (p. xvii). For example, the research of Cawelti, Rappaport, and Wood (1992) suggests that "creative activity contains simultaneity, meaning multiple activities that occur together as interdependent and ultimately inseparable elements" (p. 83).

While highly creative individuals may dynamically switch back and forth between thought processes, or parallel-process thoughts simultaneously in different ways, convergent thinking versus divergent thinking may be better understood as a continuum, rather than a dichotomy. Eysenck (2003) points out that in our rush to categorize, we often create dichotomies where none exist. Humankind's tendency to view things categorically leads us to interpret many continuums as dichotomies. Eysenck refers to Thomas Kuhn's (1970) normal science versus revolutionary science as an example. Normal science is intended to describe problem-solving within an existing paradigm, while revolutionary science is intended to change the paradigm. Eysenck also points to a parallel between three 'dichotomies': normal science versus revolutionary science; the context of justification versus the context of discovery; and convergent thinking versus divergent thinking. He explains that philosophers of science have been concerned with the context of justification (which is associated with normal science and convergent thinking) and leave the context of discovery (which is associated with revolutionary science and divergent thinking) to psychologists. So we have three parallel 'dichotomies,' all of which are more likely continuums.

Eysenck begins breaking down these dichotomies by describing two mathematicians (Hardy and Ramanujan) who are good representations of the extremes. Hardy being the convergent thinking, normal science, justification type, while Ramanujan is the divergent thinking, revolutionary science, discovery type. One follows rules and tries to prove them valid, while the other is more likely to ignore rules and show that something else entirely should replace those rules. Eysenck then goes on to illustrate that many mathematicians fall somewhere between these extremes and he argues that most of us fall somewhere between the extreme points of this continuum.

That is, an individual's thinking style is not purely divergent, or purely convergent. Neither is it a middle ground that is achieved by alternating between pure divergent thinking and pure convergent thinking. This thesis would suggest that most of us have a preferred thinking style that is somewhere between these two extremes and that this preferred thinking style will dynamically change depending on the circumstances. Eysenck (2003) presents this perspective of the convergent-divergent-thinking-as-continuum argument as well. He begins by pointing out that IQ test questions require some creativity – since the answer may not be immediately obvious to the test taker – and tests of divergent thinking still require an ordinary association of ideas. Runco (2014), agrees with this interpretation, stating that "Very likely, divergent and convergent thinking are actually two ends of a continuum" (p.10).

Multiple choice questions on an IQ test are meant to be tests of convergent thinking. However, Carson (2010) points out how the highly divergent thinker may make associations that could justify any of the choices as the correct answer. At the same time as they are divergently rationalizing each choice, they are also trying to determine which is the 'best' answer – what answer does the test writer think is the 'correct' answer – by using a convergent thinking process. The highly convergent thinker employees the same process, of trying to make associations between the question and the possible choices, but their steeper associative gradient prevents them from seeing the possible connections between the question and the 'wrong' answers. Or, as Eysenck (2003) puts it, a person who tends to employee convergent thinking can do well on multiple choice questions "with the use of a steep associative gradient, because the class of relevant associations is already implicit in the statement of the problem" (p. 105). In each case, the balance of convergent and divergent thinking used, and how far along the convergent-divergent thinking continuum each is, depends on the individual question.

Convergence tests require making multiple associations, just as in divergence tests. The only difference between the two is that only one of the associations is deemed correct in the case of the convergent test, while all associations are accepted for a divergent test.

Martindale (1999), relates the difference between convergent and divergent thinking to the speed of information processing, suggesting that more creative people are selective with their speed of information processing. A highly creative person will widen their field of attention early in the creative solving process, allowing a larger amount of information to be processed – more associations to be considered – thereby slowing their reaction time. Once the problem is better defined, they will narrow their attention span, speeding up their reaction time.

3.1.2.6 Extroverted – Introverted Continuum

Kaufman and Gregoire (2015) argue that when it comes to personality traits, highly creative people seem to be particularly good at switching back and forth on these various continua, depending on what is the most useful at the moment. They argue that "the coexistence of introverted and extroverted characteristics [is] one of the central paradoxes of creative people" (p. 130).

Extroversion is one of what has come to be known as the *Big Five* personality factors. They are broad umbrella terms under which hundreds of identified personality traits have been categorized (McNulty, 2000). The big five include openness, conscientiousness, extroversion, agreeableness, and neuroticism (Hornberg & Reiter-Palmon, 2017). Extroverts get their energy by interacting with others, while, on the other end of the spectrum, introverts derive their energy from within (123 Test, 2018). 75% of the population is considered extroverted (Psychology Today, 2018). Psychologists consider these factors to be quite stable over time, and extroversion has been shown to be the more stable of the big five (Hampson & Goldberg, 2006; Rantanen et al., 2007). However, Csikszentmihalyi (1996) has pointed out that, not only do creative people move from being introverted to extroverted as the need arises,[40] they even exhibit both traits at the same time.

How can that be? The traits that make up extroversion – friendliness, gregariousness, assertiveness, activity level, excitement seeking, and cheerfulness (Educational Testing

---

[40] He noted that the successful art student is introverted, and the successful artist is extroverted.

Service, 2018) – are thought to generally move in tandem. That is, extroverts generally score relatively high in all the traits associated with extroversion and introverts generally score relatively low in all of the traits. But, highly creative individuals can be expected to, more often than not, score low on friendliness and cheerfulness, while scoring high on assertiveness, gregariousness and excitement seeking.

Not only are creative individuals low in some extroversion personality traits, while being high in others, they also tend to change their dominant personality type, going from extroverted to introverted, depending on the situation. The psychologist Jennifer Grimes interviewed 21 metal rock musicians and found personality contradictions of openness and sensitivity, and extroversion and introversion. These musicians, who were very extroverted on-stage, were frequently introverted when not performing (S. B. Kaufman & Gregoire, 2015). This has been noted, to an even greater degree, with Michael Jackson (Leopold, 2018). Similarly, Greengross and Miller (2009) found that comedians were the most introverted when compared to humour writers and a group of university students, even though they utilize many extroversion traits for a living.

☯

In summary, highly creative people seem to exhibit paradoxes, including: knowledge – naivety; mindfulness – mind-wandering; psychological health – psychiatric disorders; executive attention network – default network; convergent – divergent-thinking; extroversion – introversion. When viewed in another way, that is, when seen from the perspective of the complexity theory of creativity, highly creative people seem to dynamically navigate multiple continua. Given this, perhaps the watchword to describe the highly creative person should be *adaptable*. The human personality is complex. It may be that the highly creative individual's personality is just a little more complex or makes use of that complexity in a different – more dynamic – way.

3.1.3 Paradoxes of Complexity

Complex adaptive systems are often described as exhibiting paradoxes (Plsek & Greenhalgh, 2001; Stacey, 1996). Stacey (1996), identified seven complexity paradoxes that exist in all organizations and affect their creativity. That is, a creative organization requires the right balance between opposing forces to achieve a level that supports creativity. In each of these areas, an organization can have too much, or too little:

- information flow,
- diversity,
- number of interconnections,
- richness of interconnections,
- contained anxiety,
- centralized control,
- power differential.

Because complex adaptive systems interact with other complex systems, they are constantly adapting, never reaching an equilibrium state, resulting in unresolved tension, paradoxes, and the OCD referred to throughout this paper.

If creativity is an emergent characteristic of complex adaptive systems, then we would expect to observe this OCD at work in creative people and in the creative process. Based on the existing creativity literature this OCD characteristic of complex adaptive systems seems to manifest as multiple paradoxes in creativity (see, for example, S. B. Kaufman & Gregoire, 2015). It seems that we are so used to thinking in terms of binaries, or dichotomies, that we lose sight of the fact that most things we measure – traits, attributes, abilities – are, in fact, continuums. While creativity researchers have begun to recognize that the results of creativity research are not so much contradictory as they are indicative of the paradoxes of creativity, there is also some recognition that there is more to it than just that. Kaufman and Gregoire noted that "armed with mounting evidence of these deep paradoxes, scientists now generally agree that creativity is not a single characteristic but a system of characteristics, and many theories now emphasize the multifaceted nature of creativity" (Kaufman & Gregoire, 2015, p. xxiv). Is there one over-arching theory that can explain these "deep paradoxes" and "the multifaceted nature of creativity"?

Complexity theory suggests we might want to take this idea one step further. When combined with everything we know about creativity, complexity theory indicates that perhaps our traits, attributes and abilities are not just points on a continuum where we each have our place, with the more creative among us possessing more attributes near the creativity-maximizing sweet-spots. Our attributes are dynamic, constantly moving, and derived from a *creative adversarial network* (defined below).

Evidence supporting the perspective of creativity paradoxes being the result of the OCD characteristic of complex adaptive systems comes from the field of Artificial Intelligence (AI). Recently, AI researchers developed a new approach to creative, computer generated art (Elgammal, Liu, Elhoseiny, & Mazzone, 2017). The results passed a sort of Turing test. That is, they tested the output against human-generated art (sourced from WikiArt and Basel) and had various people evaluate the results. The evaluators rated the images created by the computer system higher than the human-generated art. They identified with it more closely and found it more inspiring. The system starts with what is called a generative adversarial network. In this network, one AI system learns to recognize existing styles and another system generates images that get accepted or rejected by the first system so that the generating system learns to mimic existing styles. This has been the state of the art (pun intended) in AI generated art for several years. The breakthrough of the creative adversarial network was the addition of another AI system that pulled the generating system away from mimicking, getting it to deviate enough to be novel, but not so much that is no longer recognized as similar to an existing style by the first system.

For each of the continua discussed in this paper, there are contradictory research results. This is to be expected within a complexity theory of creativity. One of the main characteristics of a complexity theory of creativity – including the OCD component – is that specific outcomes can never be predicted. We can only predict patterns. This relates to the fact that, while creativity may simply be the connecting of two previously unconnected things in a way that makes sense, there are multiple ways to find the simple connections that make sense. Highly creative people will change their approach, given the circumstances of the moment. Those circumstances may be so varied that we could never expect to control them all in any experiment. For instance, a person's mood may affect how dynamic they are on the extroversion-introversion continuum, or whether they remain higher or lower on this continuum, or on any of the other continuums.

There is a great deal of circumstantial evidence indicating that creativity is the emergent of a complex system. Seeing creativity in this way can help us advance our understanding of creativity, perhaps providing better direction for how we might recognize, quantify, and enhance creativity. But there is much work left to do to develop a complete complexity theory of creativity. This paper has looked at how creativity research is consistent with one characteristic of complexity theory: the order – chaos-dynamic. If the same can be done for each of the other characteristics, then the potential exists to develop an overarching, comprehensive, complexity theory of creativity.

Creativity is a continuum (Amabile, 1996) and people exist along this continuum. However, the argument presented in this paper indicates that everyone can be expected to display tendencies to operate at multiple points along the continua previously discussed, with the expectation that more creative people will show greater extremes in their dynamics. This is different than Csikszentmihalyi's assertion that creative types show contradictory extremes, while less creative types do not. A complexity theory of creativity suggests that it is the degree of contradiction that is expected to change with the degree of creativity.

3.1.4 Conclusions and Future Research

Conceptualizing creativity as a characteristic of complex adaptive systems opens up many lines of research. For example, while this paper considered the OCD characteristic of complex adaptive systems, the argument should be extended to other characteristics. This could include fat-tailed behaviour and emergence. The congruence of an overall complex adaptive system-based theory of evolution and creativity could also be explored. There is a great deal of existing data on the success/popularity of creative outputs, including the diffusion of innovation. Much of this data could be re-analyzed to see if it supports a complexity theory of creativity. While data from the movie industry has already been shown to follow an inverse power law (another characteristic of complex adaptive systems) (De Vany, 2006; Walls, 2005), it remains to fully develop the argument that this supports a complexity theory of creativity. This work could also be extended to many other fields. For example; works of art, new consumer products, crowd-funding campaigns, and social media information flow. A more ambitious research project would be to re-examine all major creativity research findings to determine if there is any current understanding of creativity that would not fit within a complexity theory of creativity, much the way this paper has attempted to show that the known paradoxes of creativity fit within the OCD of complexity. Computer modelling could also be used to help provide corroborating evidence for an OCD view of creativity.

Further work in AI systems along these lines is warranted. Creativity paradoxes viewed as the OCD of complex adaptive systems suggests that multi-dimensional creative adversarial networks – that is, creative adversarial networks operating along multiple continua – may produce more creative AI systems.

The concept of adversarial networks[41] cooperating to result in creative output may apply broadly – to creative organizations, for example. This provides for another line of research.

Predictions that arise from viewing creativity paradoxes as being the result of the OCD characteristic of complex adaptive systems include:

- People cannot be expected to be static on other personality dimensions.
- Highly creative people will be more dynamic on those personality dimensions, exhibiting greater range, and perhaps exhibiting a higher frequency of movement.
- advances in artificial intelligence may require adversarial networks operating along multiple dimensions.
- From synapses to social systems, the most creative systems are expected to be those with an optimum level of connectedness, perhaps a small-world-network topology.

---

[41] Or, in the terminology of Beaty et al. (2016), antagonistic brain networks.

- If the OCD model extends to organizations, then it would suggest a possible refinement of Stacey's (1996) model. That is, the most creative organizations are those that dynamically adapt along the continua of centralized control, power differential, information flow, diversity, number of interconnections, richness of interconnections, and contained anxiety.

Research in each of these areas could help us better understand creativity and innovation and would help advance our understanding of complex adaptive systems. Each of these items lends itself to the development of a creativity survey instrument, with the first two holding particular promise in identifying people with high creative potential.

Bibliography

123 Test. (2018). Big Five personality theory. Retrieved February 24, 2018, from https://www.123test.com/big-five-personality-theory/

Amabile, T. M. (1996). *Creativity in context: Update to the social psychology of creativity*. Boulder, CO: Westview Press.

Arecchi, F. T. (2007). Physics of cognition: Complexity and creativity. *European Physical Journal: Special Topics*, *146*(1), 205–216. https://doi.org/10.1140/epjst/e2007-00181-0

Arthur, W. B. (2009). *The nature of technology: What it is and how it evolves*. New York, NY: Free Press.

Bak, P. (1996). *How nature works: The science of self-organized criticality*. New York, NY: Copernicus.

Barron, F. (1953). An ego-strength scale which predicts response to psychotherapy. *APJCP Journal of Consulting Psychology*, *17*(5), 327–333.

Barron, F. (1988). Putting creativity to work. In R. J. Sternberg (Ed.), *The nature of creativity: Contemporary psychological perspectives* (pp. 76–98). New York, NY.

Beaty, R. E., Benedek, M., Silvia, P. J., & Schacter, D. L. (2016). Creative Cognition and Brain Network Dynamics. *Trends in Cognitive Sciences*, *20*(2), 87–95. https://doi.org/10.1016/J.TICS.2015.10.004

Boden, M. A. (2013). Creativity as a Neuroscientific Mystery. In O. Vartanian, A. S. Bristol, & J. C. Kaufman (Eds.), *Neuroscience of Creativity*. MIT Press.

Bouchard Jr., T. J., Lykken, D. T., Tellegen, A., Blacker, D. M., & Waller, N. G. (1993). Creativity, Heritability, Familiarity: Which Word Does Not Belong? *Psychological Inquiry*, *4*(3).

Brenner, G. H. (2018). Your Brain on Creativity. Retrieved March 17, 2018, from https://www.psychologytoday.com/blog/experimentations/201802/your-brain-creativity

Carson, S. (2010). *Your creative brain: Seven steps to maximize imagination, productivity, and innovation in your life*. San Francisco, CA: Wiley.

Cromwell, R. L. (1968). Stimulus redundancy and schizophrenia. *The Journal of Nervous and Mental Disease*, *146*(5), 360–375.

Csikszentmihalyi, M. (1996). *Creativity: Flow and the Psychology of Discovery and Invention*. New York, NY: HarperCollins Publishers.

De Vany, A. (2006). The Movies. In V. A. Ginsburgh & D. Throsby (Eds.), *Handbook of the Economics of Art and Culture*. Boston, MA: Elsevier.

Dykes, M., & McGhie, A. (1976). A comparative study of attentional strategies of schizophrenic and highly creative normal subjects. *The British Journal of Psychiatry : The Journal of Mental Science*, *128*, 50–56.

Educational Testing Service. (2018). Facets of the Big Five. Retrieved March 3, 2018, from https://www.ets.org/s/workforce_readiness/pdf/21332_big_5.pdf

Elgammal, A., Liu, B., Elhoseiny, M., & Mazzone, M. (2017). CAN: Creative Adversarial Networks, Generating "Art" by Learning About Styles and Deviating from Style Norms. Retrieved from http://arxiv.org/abs/1706.07068

Eysenck, H. J. (1993). Creativity and Personality: Suggestions for a Theory. *Psychological Inquiry*, *4*(3), 147–178. https://doi.org/10.1207/s15327965pli0403_1

Eysenck, H. J. (1995). *Genius: The Natural History of Creativity*. Cambridge, UK: Oxford University Press.

Eysenck, H. J. (2003). Creativity, personality and the convergent-divergent continuum. In M. A. Runco (Ed.), *Perspectives on creativity research. Critical creative processes* (pp. 95–114).

Cresskill, NJ: Hampton Press.

Fasko, D. (2011). Associative Theory. In M. A. Runco & S. R. Pritzker (Eds.), *Encyclopedia of Creativity* (pp. 135–140). London, UK: Academic Press.

Fodor, E. M. (1995). Subclinical manifestations of psychosis-proneness, ego strength, and creativity. *PAID</cja:jid> Personality and Individual Differences*, *18*(5), 635–642.

Ford, C. M. (1995). Creativity is a Mystery: Clues from the Investigators' Notebooks. In C. Ford & D. Gioia (Eds.), *Creative Action in Organizations: Ivory Tower Visions & Real World Voices* (pp. 12–50). Thousand Oaks, CA: SAGE Publications, Inc. https://doi.org/10.4135/9781452243535

Greengross, G., & Miller, G. F. (2009). The Big Five personality traits of professional comedians compared to amateur comedians, comedy writers, and college students. *PAID Personality and Individual Differences*, *47*(2), 79–83.

Hampson, S. E., & Goldberg, L. R. (2006). A First Large Cohort Study of Personality Trait Stability Over the 40 Years Between Elementary School and Midlife. *Journal of Personality and Social Psychology*, *91*(4), 763.

Holland, J. H. (2012). Signals and boundaries: Building blocks for complex adaptive systems. Cambridge, Mass.: MIT Press. Retrieved from http://public.eblib.com/choice/publicfullrecord.aspx?p=3339466

Holland, J. H. (2014). *Complexity: A Very Short Introduction*. Oxford, UK: Oxford University Press.

Hornberg, J., & Reiter-Palmon, R. (2017). Creativity and the Big Five Personality Traits. In G. J. Feist, J. C. Kaufman, & R. Reiter-Palmon (Eds.), *The Cambridge Handbook of Creativity and Personality Research* (pp. 275–293). Cambridge: Cambridge University Press. https://doi.org/DOI: 10.1017/9781316228036.015

IBM. (2010). IBM 2010 Global CEO Study: Creativity Selected as Most Crucial Factor for Future Success. Retrieved November 11, 2016, from https://www-03.ibm.com/press/us/en/pressrelease/31670.wss

Kauffman, S. A. (1995). *At home in the universe: The search for laws of self-organization and complexity*. New York, NY: Oxford University Press.

Kaufman, S. B. (2013). After the Show: The Many Faces of the Creative Performer. Retrieved April 15, 2018, from https://blogs.scientificamerican.com/beautiful-minds/after-the-show-the-many-faces-of-the-creative-performer/

Kaufman, S. B., & Gregoire, C. (2015). *Wired to create: Unraveling the mysteries of the creative mind*. New York, NY: Penguin Random House LLC.

Kyaga, S., Lichtenstein, P., Boman, M., Hultman, C., Långström, N., & Landén, M. (2011). Creativity and mental disorder: Family study of 300 000 people with severe mental disorder. *The British Journal of Psychiatry*, *199*(5), 373 LP-379. Retrieved from http://bjp.rcpsych.org/content/199/5/373.abstract

Lambert, P. A. (2017). Understanding Creativity. In J. B. Cummings & M. L. Blatherwick (Eds.), Creative Dimensions in Teaching and Learning in the 21st Century (pp. 1–21). Rotterdam: Sense Publishers. https://link.springer.com/chapter/10.1007/978-94-6351-047-9_1

Lambert, P. A. (2018). The Ontological Emergence of Creativity. Manuscript Submitted for Publication.
https://www.researchgate.net/publication/329210950_The_Ontological_Emergence_of_Creativity

Leopold, T. (2018). The confusing legacy of Michael Jackson - CNN.com. Retrieved February 25, 2018, from http://www.cnn.com/2010/SHOWBIZ/Music/06/21/michael.jackson.legacy/index.html

Lobo, I. (2008). Biological complexity and integrative levels of organization. https://doi.org/10.1126/science.101.2618.209

Martindale, C. (1999). Biological Basis of Creativity. In R. J. Sternberg (Ed.), *Handbook of Creativity* (pp. 137–152). New York, NY: Cambridge University Press.

McNulty, J. L. (2000). Five-factor model of personality. In A. E. Kazdin (Ed.), *Encyclopedia of Psychology, Vol. 3.* (pp. 375–376). New York, NY: American Psychological Association. https://doi.org/10.1037/10518-183

Mednick, S. a. (1962). The associative basis of the creative process. *Psychological Review*, *69*(3), 220–232. https://doi.org/10.1037/h0048850

mmpi-info | Supplementary Scales. (2011). Retrieved February 18, 2018, from https://www.mmpi-info.com/supplementary-scales

Plsek, P. E., & Greenhalgh, T. (2001). The challenge of complexity in health care. *BMJ : British Medical Journal*, *323*(7313), 625–628. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1121189/

Psychology Today. (2018). Extroversion | Psychology Today. Retrieved February 24, 2018, from https://www.psychologytoday.com/basics/extroversion

Rantanen, J., Metsapelto, R.-L., Feldt, T., Pulkkinen, L., & Kokko, K. (2007). Long-term stability in the Big Five personality traits in adulthood. *Scandinavian Journal of Psychology*, *48*(6), 511–518. https://doi.org/10.1111/j.1467-9450.2007.00609.x

Richards, R. (2001). Millennium as Opportunity: Chaos, Creativity, and Guilford's Structure of Intellect Model. *Creativity Research Journal*, *13*(3–4), 249–265. Retrieved from https://login.proxy.hil.unb.ca/login?url=http://search.ebscohost.com/login.aspx?direc t=true&db=aph&AN=5673217&site=ehost-live&scope=site

Robilliard, D. (2013). John H. Holland: Signals and boundaries: building blocks for complex adaptive systems : MIT Press, 2012. *Genetic Programming and Evolvable Machines*, *14*(2), 279–280.

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). New York, NY: Free Press.

Runco, M. A. (2014). *Creativity: Theories and Themes: Research, Development, and Practice*. Elsevier Science.

Sawyer, K. R. (2012). *Explaining Creativity: The Science of Human Creativity* (2nd ed.). New York, NY: Oxford University Press.

Sawyer, R. K. (1999). The emergence of creativity. *Philosophical Psychology*, *12*(4), 447–469. https://doi.org/10.1080/095150899105684

Seeley, W. W., Menon, V., Schatzberg, A. F., Keller, J., Glover, G. H., Kenna, H., … Greicius, M. D. (2007). Dissociable Intrinsic Connectivity Networks for Salience Processing and Executive Control. *The Journal of Neuroscience*, *27*(9), 2349 LP-2356.

Stacey, R. D. (1996). *Complexity and Creativity in Organizations*. San Fransisco, CA: Berrett-Koehler Publishers, Inc.

Sternberg. (1999). *Handbook of Creativity*. Cambridge University Press. Retrieved from https://books.google.ca/books?id=d1KTEQpQ6vsC

Tadić, B., Dankulov, M. M., & Melnik, R. (2017). Mechanisms of self-organized criticality in social processes of knowledge creation. *Physical Review E*, *96*(3).

Tardif, T. Z., & Sternberg, R. J. (1988). What Do We Know About Creativity? In R. J. Sternberg (Ed.), *The nature of creativity: Contemporary psychological perspectives* (pp. 429–440). New York, NY: Cambridge University Press.

Walls, W. D. (2005). Modeling Movie Success When “Nobody Knows Anything”:

Conditional Stable-Distribution Analysis Of Film Returns. *Journal of Cultural Economics*, *29*(3), 177–190.

Zhukov, D. S., Kanishchev, V. V, & Lyamin, S. K. (2016). Application of the Theory of Self-Organized Criticality to the Investigation of Historical Processes. *SAGE Open*, *6*(4), 2158244016683216. https://doi.org/10.1177/2158244016683216

3.2 The Complex Adaptive Process of Innovation Diffusion

Abstract

Through statistical analysis of six data sets, this paper challenges the long-held assumption that diffusion of innovation adoption rates are normally distributed. That is, that the number of new adopters of an innovation increases slowly at first, accelerates, reaches a maximum, then tapers off, thus yielding the classic, symmetrical, normal distribution curve and its associated cumulative probability distribution, the S-curve. From Rogers (2003) to Christensen (1997), Moore (2014), and Downes and Nunes (2013), this normality-assumption is pervasive throughout innovation theory and research. Quantitative evidence that challenges the normality-assumption is presented here. Diffusion data for six different innovations were analyzed, revealing no discernible frequency distribution pattern. This result – no consistent distribution pattern – is what we should expect if each diffusion curve is the result of a small-world social network with differing parameters. This paper examines the explanatory power of complex adaptive systems and their characteristic small world networks for understanding and managing creativity and innovation.

Keywords: diffusion of innovation; complexity science, complex adaptive systems, innovation, creativity.

3.2.1 Introduction

Creativity is often defined as coming up with something that is new and of value, or adaptive (Carson, 2010). This paper is grounded in the understanding that creativity is the necessary precursor to innovation – that is, innovation is applied creativity (K. Robinson, 2011). Thus, the diffusion of innovations is frequently part of the creative process. When 'of value' or 'adaptive' is part of the definition of creativity, then the extent of diffusion of an innovation must be one measure of how creative an innovation is.[42]

This paper is part of a larger research program to help determine if complexity theory is a viable model for explaining creativity. Complex adaptive systems exhibit randomness, but they also often reveal patterns, such as the power law distributions of many natural events. That is, when the size of natural events – such as earthquakes, landslides, or hurricanes – is plotted against the frequency of occurrence, the result is a power law distribution[43] showing many very small events and a decreasing number of larger events. See Figure 8., for example. If creativity is the result of complex adaptive systems, we can expect to see an element of randomness along with some patterns in the data related to creativity. For example, Figure 12 shows the power-law pattern that emerges when the box office

---

[42] This point could be debated, of course, but it should be clear that if an innovation does not diffuse very far, then it has no value to the portion of society that it has not adopted it. Also, in the evolution of anything (culture, technology, society, or biological entities), something novel that is not adopted (that is, something that does not diffuse very far) cannot be considered selected or retained. This could lead to a discussion regarding degrees of selection and retention, which is beyond the scope of this paper.

[43] To be more precise, the result is an inverse power law, but the details of the difference are not important to this discussion.

results for the top 5000 movies are plotted as a histogram. What appears to be random, based on the results of this paper, are the paths followed by each individual release. Some may follow a classic S-curve, while others will rise very quickly then taper off, while others will take a long time to build up before accelerating and eventually tapering off.

This leads to the research question addressed in this paper: are diffusion of innovations data normally distributed, or do they fit a power law distribution, or some other common distribution? While the thesis of this paper is that the diffusion profile for each innovation is unique because it is the result of a complex adaptive system.

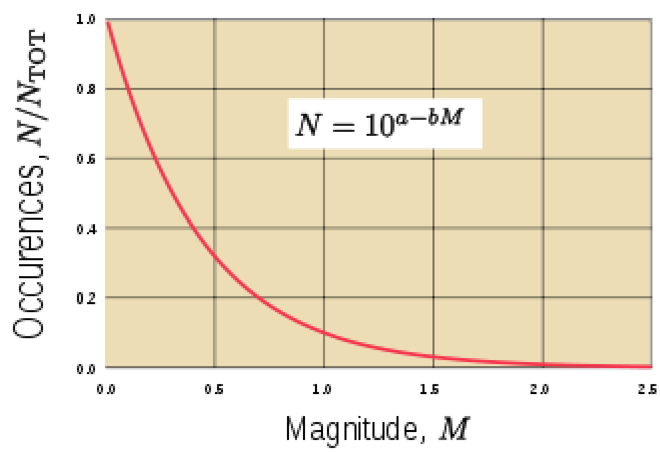


Figure 8: Gutenberg–Richter Law Expresses the Relationship Between the Frequency and Magnitude of Earthquakes (Source: https://en.wikipedia.org/wiki/Gutenberg%E2%80%93Richter_law)

The Normality Assumption: For decades the rate of adoption of an innovation has been thought to start out slowly and steadily increase until the rate reaches an inflection point and begins to decrease, eventually forming the widely recognized bell-curve (for example, see: Christensen, 1997; Moore, 1991; Rogers, 1962; 2003). That is, when the number of people adopting an innovation is plotted over time, the curve is bell-shaped (see Figure 9). This frequency distribution is variously known as a normal distribution or a

Gaussian distribution. If, instead of plotting the number of new adopters for each unit of time, the cumulative number of adopters is plotted, the result is the S-curve (Figure 9).

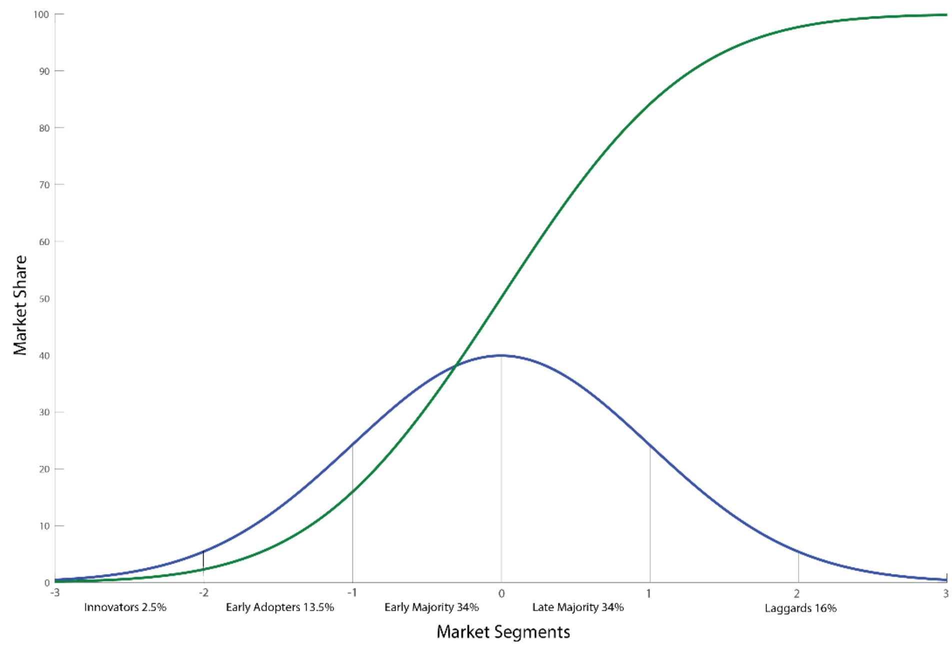


Figure 9: Normal Distribution and Cumulative Normal Distribution

The diffusion of innovations is generally viewed as a social process (Rogers, 2003) influenced by social networks, while social networks have been shown to exhibit *small-world network*[44] properties (Easley & Kleinberg, 2010; Milgram, 1967). Small-world networks have several parameters that affect the diffusion of information and the adoption rate of an innovation. If the adoption of each individual innovation propagates through its own unique small-world network, each with its own unique set of parameters, can we expect *any*

---

[44] Small world networks will be described later in the paper, for now it should be sufficient to know that the popularized term "six degrees of separation" is a key property of small world networks.

characteristic adoption frequency distribution? If not, what are the implications for innovators trying to get their creative product widely adopted?

This paper will present a brief history of diffusion of innovation theory, the problems and limits of existing theory, a basic overview of the theory of complex adaptive systems, how small-world networks fit into complex adaptive system theory, and how small-world social networks may present a better basis for diffusion of innovation theory. The results from the analysis of six sets of diffusion data are then presented. The data were analyzed to determine their likely distribution and whether they might provide evidence supporting a departure from the decades-old normality-assumption. The paper concludes with a discussion of the results, conclusions, and recommendations for future research.

Rogers' (2003) definition of innovation: "an idea, practice, or object that is perceived as new by an individual or another unit of adoption" (p. xx) provides a useful starting point for this analysis. It is a broad definition that encompasses anything new, even things of questionable value. From new products to social practices and conventions, through to new words, memes, creative works, styles, and genres, if it's new and can spread throughout all or part of human civilization by way of human decisions and proactive action it is, by this definition, an innovation.

3.2.2 Background

3.2.2.1 Diffusion of Innovations

3.2.2.1.1 History

Gabriel Tarde was a French lawyer, and one of the forefathers of social psychology. He was also the first person known to have theorized about commonalities in the diffusion of innovations, which he called the laws of imitation. He wondered why approximately ten percent of innovations went on to be adopted in many countries while the rest were forgotten (Rogers, 2003, Tarde & Parsons, 1903). Tarde said the supreme law was that of indefinite progression, which he related to the facts that everything repeats, and nothing persists. That is, every invention must overcome many obstacles to adoption,[45] and every invention is eventually replaced. Tarde also noted that innovation flows freely within a group of similar people, from upper classes to lower, and from conquerors to conquered peoples. In other words, he saw imitation flowing down, from the superior state to the inferior, and from higher rungs of the social ladder to the lower. Tarde claims that examples of imitation flowing in the other direction are practically non-existent (Tarde & Parsons, 1903).

Following Tarde, in the early twentieth century, some early European social scientists expressed the view that all social change could be explained solely by diffusion. These early *infusionists* had an indirect influence on Ryan and Gross' 1941 study of the diffusion of hybrid corn seed (Rogers, 2003). Ryan and Gross studied the diffusion of hybrid corn seed in two Iowa communities and concluded that the process of diffusion of innovations did not lend itself to simple statistical prediction and that the pattern of adoption could not be accurately described as a normal distribution. They also noted that there were sharp contrasts between the extreme adoption groups (that is, between the earliest and latest adopters) in certain conditions, but that these same conditions did not provide for any distinction within the much larger intermediate group. Ryan and Gross concluded that the conditions which would lead to earlier adoption included being socially active, young, better educated, and with a

---

[45] Tarde uses *imitation* in similar way to how *adoption* is used in today's diffusion of innovation literature. *Adoption* is used here for clarity.

larger scale farming operation. They summarized the difference as the urbanization of rural behaviour – the more urbanized farmers being more likely to adopt an innovation early (Ryan & Gross, 1943, 1950).

Although Ryan and Gross argued that the pattern of adoption was not a normal distribution and, in fact, that there was insufficient consistency to be able to make predictions, Everett Rogers argued that diffusion is a general process that explains social change of any type and shows similar characteristics across specific instances.

3.2.2.1.2 Rogers

Rogers (2003), defines diffusion as "the process in which an innovation is communicated through certain channels over time among the members of a social system. It is a special type of communication, in that the messages are concerned with new ideas" (p. 5). He divided the diffusion process into four main elements: the innovation, communication channels, time, and the social system (note the relationship to his definition of diffusion). Rogers also identified five characteristics of innovations that explain differences in rates of adoption: relative advantage, compatibility, complexity, triability, and observability. Each of these characteristics either influences the perceived level of risk or provides an incentive for accepting the risk of adopting something new. The five main steps Rogers identified in the innovation-decision process are knowledge acquisition, persuasion, decision, implementation, and confirmation. Finally, Rogers divided the diffusion curve into five parts and painted a picture of the adopters that can be expected at each stage: innovators, early adopters, early majority, late majority, and laggards. Rogers' conclusion that diffusion progresses following a normal distribution curve led him to apply the statistical properties of such a curve and conclude that 2.5% of the population will be innovators, 13.5% early adopters, 34% early majority, 34% late majority, and 16% laggards.

3.2.2.1.3 Other Diffusion of Innovation Theories

Rogers (2003) argues that innovativeness – the variable along the x-axis of Figure 9 – is a continuous variable and, therefore, there cannot be any gaps. Almost 30 years after the publication of the first edition of Roger's *Diffusion of Innovation* (1962), Geoffrey Moore noticed a challenge many companies had reaching the early majority, after successfully marketing their products to early adopters. While he praised the value of the diffusion of innovations theory – or the technology adoption lifecycle, as he refers to it – he argues that its main flaw is in assuming smooth curves.

Moore's arguments are based on a business to business focus (Moore, 1991; Schawbel, 2015), while Rogers' theories seem to be based on business (or organization) to consumer communication. This appears to be one of the reasons Rogers sees innovativeness as a continuous variable, while Moore sees it as discontinuous, having at least one gap. However, the gap that Moore sees between the early adopters and the early majority is very similar to what Rogers describes as the slow diffusion from innovators to early adopters. Furthermore, some of the most successful products, which make for some of the most interesting diffusion case studies, follow a technology adoption cycle that begins with businesses, then expands to consumers. In this case, even within the same product, there are essentially two different adoption life cycles, one for businesses and one for consumers. Each has its early adopters, early majority, and each of the other adopter types. In these cases, the early majority in business plays the role of the early adopter for consumers, paving the way for more rapid diffusion in the consumer market. For example, the internet and email were becoming common in business before they were widely available to general consumers.

While there may be some differences between Rogers' and Moore's theories, they both agree that the process of adoption is a social process. People do what they see other people doing, particularly people whose opinion they respect, and people they have much in common with. Until a tipping point is reached, increased adoption requires more and more marketing effort. Rogers calls it reaching critical mass, after which, adoption becomes self-sustaining. While Moore argues that the diffusion adoption curve is not smooth, all representations of his model (see Figure 10) suggest he sees the normal distribution as an underlying assumption – a starting point. He only argues for one gap in this otherwise smooth curve. This one gap (chasm) may or may not be crossed as a company transitions from customers who are considered early adopters to those who are the early majority.

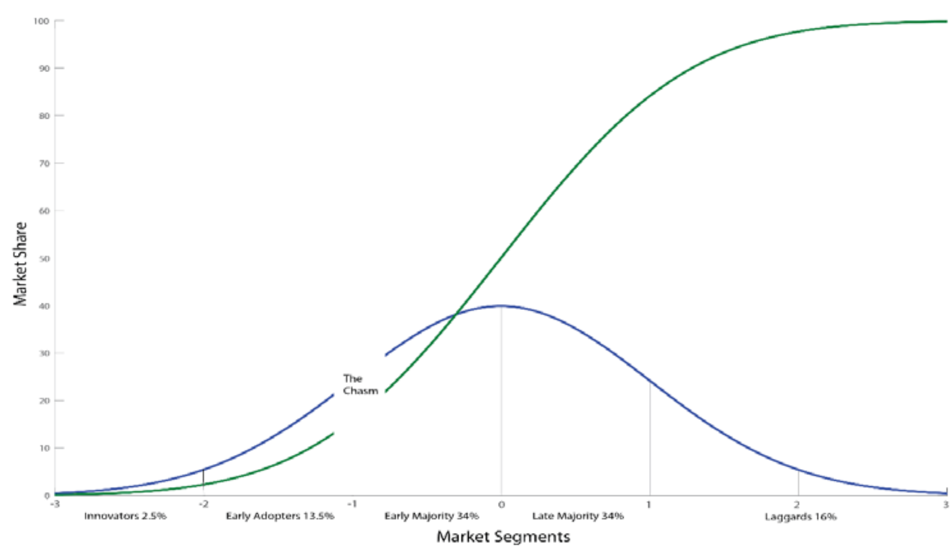


Figure 10: Moore's Chasm (Adapted from Moore, 2002)

Extending this discussion to today's highly-connected world of internet commerce, Downes and Nunes (2014) propose that the bell curve and the resultant S-curve of diffusion/adoption are dead. They claim that because of changes in technology the curve now consists only of two segments – trial users, and everybody else – and that the curve has been severely shortened in the horizontal direction. In their model, the adoption curve goes almost straight up after reaching the 'vast majority' segment. It also comes back down almost as quickly. However, their model (see Figure 11) just shows a normal distribution with different parameters, that is, with a smaller standard deviation and with perhaps a little skewness. They argue that this is a model that applies to disrupters – companies that radically change the status quo. They accept that the standard model (Roger's) may apply to regular products and markets, but for products that are disrupting markets, theirs, they claim, is the new model. The implication is that they see the diffusion of innovation happening in one of two ways – slowly, or quickly.

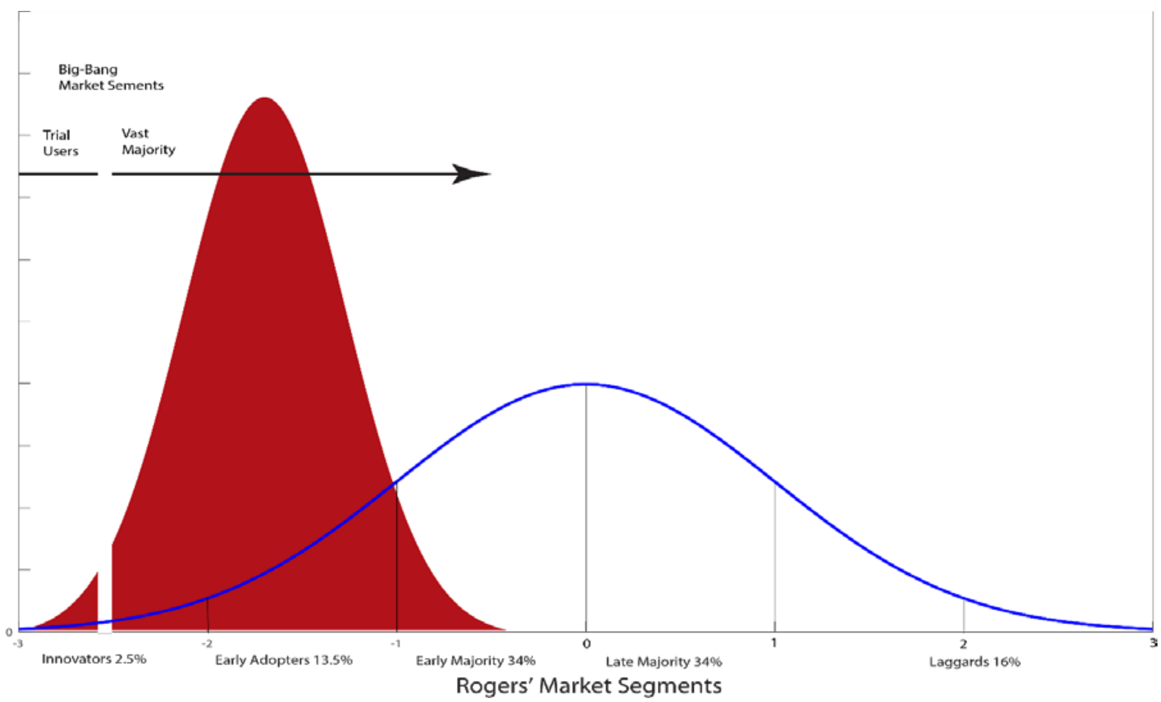


Figure 11: Big Bang Disruption (Adapted from Downes & Nunes, 2014)

In yet another analysis of the S-curve, Christensen (1997) explores why some well-run companies are seemingly blind-sided by technology upstarts. Christensen (1992) claims there are limits to the technological S-curve, which many scholars have declared is the key to managing technology development strategically. The S-curve, in this case, is very closely related to the diffusion of innovations S-curve. The essential difference is in perspective. The diffusion of innovations S-curve is best interpreted as taking the point of view of the consumer. The technology S-curve can be thought of as taking the research and development department's point of view.[46] While Christensen's thesis has little to do with the shape of the technology adoption life cycle, his work reveals this underlying assumption.

3.2.2.1.4 Problems and Limitations

While theories of innovation diffusion assume a normal distribution, there has been research over the years that looks at specific examples where the normal distribution has not applied.

Long tails, slow starts and lingering deaths: The *productivity paradox* refers to the observation that long-expected productivity gains from the increasing use of computers have not materialized. There has been a "clash of expectations of and statistics" (Brynjolfsson,

---

[46] Consider, for example, the diffusion of the home computer. This is best viewed as one long diffusion curve, taking place over decades, with no consideration for changes in internal details. The technology S-curve, on the other hand would relate to things such as the evolution of the CPU, with its increasing clock speed, change from 32 bit to 64 bit architecture, the introduction of multi-threading, moving from single core to multi-core processors, larger caches, and increasingly smaller sizes as technology used in the manufacture of CPUs – stereo lithography – goes through its own technology life cycle. This nested technology life cycle often extends many layers deep and becomes circular. That is, many technologies depend on metals and other materials as inputs. Materials science is a constantly evolving field, as are the extraction technologies used to obtain the raw ingredients to be processed into advanced materials. These extraction technologies themselves benefit from advances in materials science.

1993). In a more general sense, the productivity paradox refers to any instance when a new technology is not delivering the expected increases in productivity.

David (1990), argues that this is typical when any type of general purpose engine diffuses throughout a socio-economic system. David describes a general-purpose engine as "key functional components embodied in hardware that can be applied as elements or modular units of the engineering designs developed for a wide variety of specific operations or processes" (p. 355). In addition to the computer, he cites the steam engine and the dynamo as examples that did not produce the productivity gains expected, in the timeframe expected. David suggests that there are several issues that lead to this paradox. One of the larger issues is that the transition to a new 'techno-economic regime' requires a considerable amount of time for supporting infrastructure to adjust. Also, methods, procedures, and modes of thinking take time to adjust while industries slowly determine how to fully capitalize on the new technology. Sunk costs must also be taken into account when considering the replacement of still-serviceable technology from the old regime, often slowing down investment in the new technology.

While the productivity paradox deals with the slower-than-expected diffusion of innovation, the other end of the innovation life-cycle has also been shown to extend out further than a normal distribution would lead us to expect. That is, some technologies live long past when they were expected to be replaced by something else. Examples include the carburettor, optical photolithographic alignment technology, CISC processor architecture, and manual typesetting (Henderson, 1995; Snow, 2004, 2008).

Snow's research (2004, 2008), indicates two reasons for what he calls a technology's *last gasp*. First, the threatened technology is forced out of markets where it is least competitive. As a company abandons areas where its technology is less competitive, its relative, average performance improves. Secondly, Snow found that the old technology may borrow some aspects of the technology that is threatening it. For example, when Electronic Fuel Injection (EFI) was introduced in the automotive market, it looked like carburettors would experience a quick death. However, carburettors made use of the electronic fuel control systems, developed to enable EFI, to improve fuel economy and remain competitive much longer than initially expected.

Henderson's (1995) researched the "unexpectedly long old age of optical lithography." He points out how the predicted limits of optical photolithography have been exceeded many times over, throwing into question the belief "several authors have… that one can predict the limits of a technology from a knowledge of the laws of physics" (p. 631). For instance, Henderson points out that industry experts predicted (around 1995, when he wrote the paper) that the wavelength of visible light would limit the performance of optical aligners to about 20 μm. With the benefit of hindsight, we can now see that Henderson was right. More than 20 years after Henderson wrote about the unexpectedly long old age of optical lithography, immersion lithography now goes down to 32 nm and the next generation lithography is expected to go down to 22-16 nm (1,000 times smaller than the previously predicted limit) using extreme ultraviolet, X-ray, electron beam or ion beam technology.

Nobody Knows Anything: Referring to the movie industry, Goldman (1983) once opined that "nobody knows anything." Goldman was referring to the fact that, even with all of the experience, analysis, focus groups, and market analysis of Hollywood studios, no one has any idea how well a movie will do before it is released. De Vany's (2006) research shows that box office revenues follow a power law[47] distribution rather than a normal distribution. Large-scale events are more likely in a system with a power law distribution than in one with a normal distribution. These large events, far out on the tail of the distribution, dominate any sample statistics, making the concept of an average meaningless, as noted by De Vany: "for some variables, even the mean does not exist." These extreme events also lead to a variance measure that tends toward infinity as more samples are collected. Therefore, movie box office receipts have no natural scale, and the words *typical*, or *average,* do not apply – they lose their meaning in a power law system. An example might help. Figure 12 shows the top box office receipts of the top 5,000 movies arranged in a histogram with bin sizes of $50,000,00. The first category, which represents movies grossing from $17 – 67,000,000, contains more than half of the total number of movies in this database – 2,916 out of the total of 5,000. The difference between this and the frequency of the largest categories is so large, that we those largest categories are not visible (there is one movie that registers in the highest category). The average box office revenue for all 5,000 movies is $115,681,618. In this case, the average does not tell us much about the data set, since there are 1320 movies that earned more than this and 3680 movies that earned less. The four movies that earned more than $2 billion have a much larger impact on the calculation of the average than the 2,916 movies that earned $17-67 million. Another 10 movies earning $50 million would have little impact on the average, but one movie earning $3 billion would have a meaningful impact on the average. For data that follows a normal distribution, 68% of all data falls within one standard

[47] De Vany actually refers to the distribution as "the stable Paretian distribution," but since the Paretian distribution is a particular power law distribution, the more general term – power law distribution – will be used here in order to maintain consistency with the terminology in other parts of this paper.

deviation of the average. For this data set, the standard deviation is $175,944,691 – such a large number that one standard deviation below the average results in a negative number.

De Vany points out that studios have adopted business practices that are "rational adaptations" to the uncertainty that is characteristic of systems best modelled with a power law. This uncertainty, and the power-law distribution, are characteristics of complex systems – the topic of the next section.

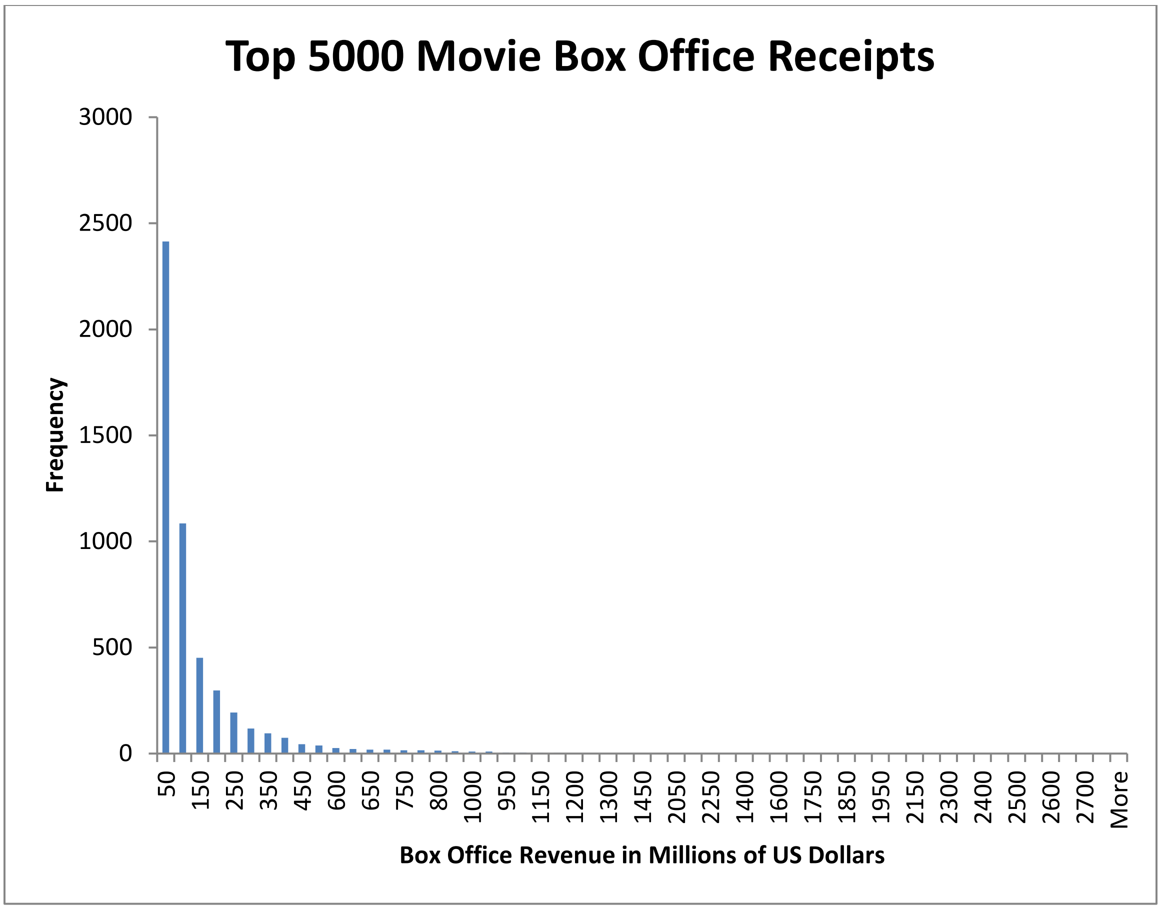


Figure 12: Box Office Receipts (Data Source: https://www.the-numbers.com/box-office-records/worldwide/all-movies/cumulative/all-time)

3.2.2.2 Alternative Conceptual Framework: Complexity Theory and Small-World Social Networks

Holland (2014), describes two distinct types of complex systems: complex physical systems, which he defines as "arrays of elements, in which interactions typically depend only on effects propagated from nearest neighbours" (p. 6), and complex adaptive systems, which are defined as having many diverse, interconnected, interdependent elements (referred to as agents) adapt their behaviour based on interactions with other agents and their environment (Page, 2009a). Within such systems, complex behaviours often emerge due to nonlinear responses to changes. The range of interactions – breadth and depth – and adaptation are the key differentiators between complex physical systems and complex adaptive systems. When it comes to the diffusion of innovations, we only need to be concerned with complex adaptive systems, examples of which include the human brain, all living organisms, human societies, and colonies of social insects.

While there are many different characteristics associated with complex adaptive systems, this paper is only concerned with *emergence*, and *small-world networks*.

3.2.2.2.1 Emergence

Emergence is the appearance of a novel characteristic that could not have been predicted by studying the properties of the individual agents and their interactions. Agents self-organize, with low-level rules giving rise to unforeseen properties and behaviours at the higher, system level. Examples include human societies, cities and the stock market arising from the interactions among people; life arising out the interactions among cells; consciousness arising from the interactions of synapses; and the intelligent behaviour of ant colonies arising from many individual ants following simple rules. In these systems, the agents influence the higher-level system, and the system influences the agents. Emergence can also take place over multiple levels. For example, macromolecules such as proteins emerge from the interaction of molecules; macromolecules form cells, cells form tissue, tissues form organs and organ systems, organs form organisms, organisms form populations, populations form communities, social systems and ecosystems, and ecosystems form biospheres (Lobo, 2008). In these systems, individual agents affect the higher level emergent, and the emergent effects the lower level agents. "A very small change in a single macromolecule can have a profound effect on an organism, or even a population, when magnified through levels of complexity" (Lobo, 2008, p. 210). This paper is grounded in the concept that creativity is an emergent property of all complex adaptive systems. The emergent characteristics of a complex adaptive system are new, novel, unexpected, and adaptive, just as creativity is often defined as the development of something novel and of value, or adaptive.

3.2.2.2.2 Small-world Networks

The diffusion of innovation is a social process which depends, at least in part, on the communication channels of a social system (Rogers, 2003). Human social systems are now recognized and studied as small-world networks, a concept which has been popularized as the *six-degrees of separation* concept and the *six degrees of Kevin Bacon* (Watts, 1999). See Figure 14 for a simplified representation of a small-world network.

As stated earlier, a complex adaptive system is one in which diverse, interconnected, interdependent elements adapt their behaviour based on interactions with other agents and their environment. The small-world network topology is just one possible arrangement of these interconnected agents; however, it turns out to be a common one in complex adaptive systems, including networks as diverse as the human brain, social networks, the internet (Easley & Kleinberg, 2010) and food webs (Montoya & Sol, 2002).

Watts and Strogatz (1998) defined the term small-world networks "to refer to networks with high local clustering and short global path lengths" (Watts, 2004, p. 245). Examples can be seen in Figure 13 and Figure 14. Notice there are various areas of the network where there are a lot of interconnections – that is, high local clustering – and there are links between these groups, resulting in short global path lengths[48]. The tightly-linked regions of the network are often dominated by strong ties – that is, social contacts that have frequent, close interactions – while the connections that cross regions are often weaker ties, of a more casual nature (Easley & Kleinberg, 2010).

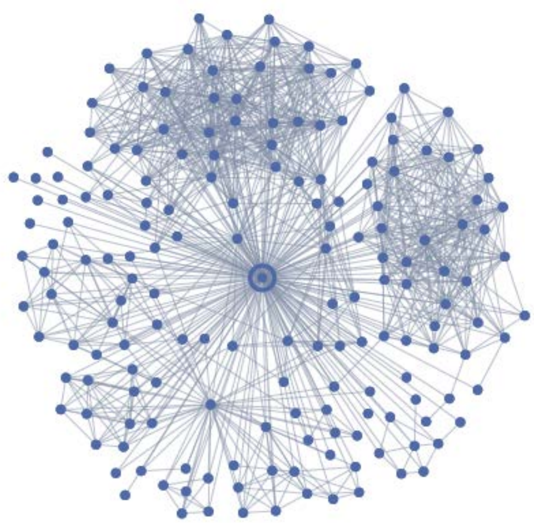


Figure 13: A Facebook User's Network Neighbourhood (Source: https://www.facebook.com/notes/facebook-data-science/maintained-relationships-on-facebook/55257228858/)

[48] The path length is the number of steps between nodes that must be traversed to get from one node to another. The global path length, also referred to as the average path length, is the average number of steps, taking the shortest path, between all possible pairs of nodes in the system.

Stanley Milgram (Travers & Milgram, 1969) was the first to gather experimental evidence to support the small world concept. Milgram asked 294 individuals in Boston and Nebraska to try to get a message to a target person "using only a chain of friends and acquaintances" (Milgram, 1967, p. 64). The target person was chosen at random, lived in the United States, and was the same for all individuals who participated. Milgram's first study of this type resulted in a median path length of five and a mode of six, giving rise to the term six-degrees of separation.

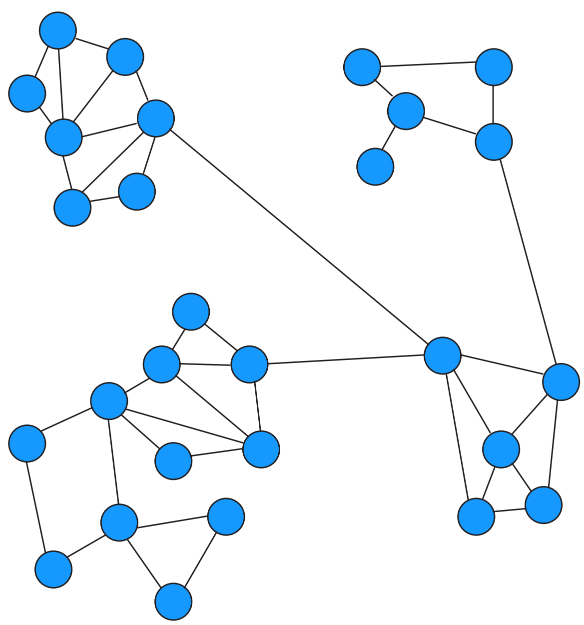


Figure 14: Small World Network Example

The next major advance in the study of small world networks came when Watts and Strogatz (1998) illustrated graphically and mathematically how small-world network topology works. They noted how, up until then, network research was ordinarily carried out under the assumption of either a completely regular or a completely random network topology. A regular network is one that is highly ordered (see the diagram on the left of Figure 15), with each node being connected to the same number of its nearest neighbours. The nodes of the regular network in Figure 15 are each connected to their four nearest neighbours. In a random network (the diagram on the right in Figure 15), each node may still have the same number of connections, but the connections are not necessarily to the node's nearest neighbours. Instead, the connections are random. Between these two extremes are networks with some nearest-neighbour connections and some random connections.

Watts and Strogatz showed how replacing each connection in a regular network with a random connection, with a probability of p, results in the average distance between any two nodes dropping off rapidly (that is, the path length L being the number average number of steps between any two nodes), even while local clustering (clustering coefficient C) remains high (see Figure 15 and Figure 16). The clustering coefficient is a measure of the interconnectedness of nearest-neighbours. When all nearest neighbours are connected, as in a regular network, the clustering coefficient is equal to one. The clustering coefficient drops off to near-zero for a random network. As can be seen from Figure 16, even a small change from a highly structured, regular network (that is even small probabilities: P) results in a much shorter average path length. As Watts and Strogatz put it "each shortcut has a highly nonlinear effect on L, contracting the distance not just between the [nodes] that it connects, but between their immediate neighbourhoods, neighbourhoods of neighbourhoods, and so on" (p.440). From a practical standpoint, this means that, while we might have a relatively small group of highly interconnected friends and acquaintances in our geographic area,[49] we only need to know someone who knows someone in another geographic area to result in a relatively short path-length to anyone else in the world.

---

[49] Depending on what it is that is being studied, geographic distance can be replaced with other factors that separate us from other social groups. For example, if you belong to two different online groups, you could be the short-cut between those two groups.

In their 1998 letter to the publication *Nature*, Watts and Strogatz predicated that small world networks would prove "to be widespread in biological, social and man-made systems, often with important dynamical consequences" (Watts & Strogatz, 1998, p. 442). This statement would prove to be correct, if somewhat understated. The small world phenomenon has been identified in social networks of all kinds, including friendship networks, email communication networks, and online social networks. It has also been identified in the internet itself, weblinks, loans among financial institutions, and manufacturing supply networks (Easley & Kleinberg, 2010).

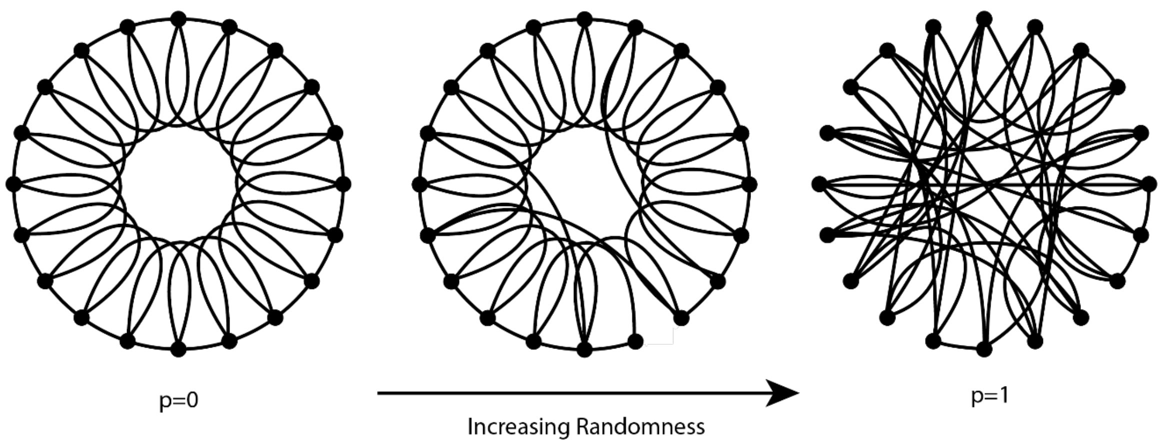


Figure 15: The Small World Concept in a Ring Network (Adapted from Watts & Strogatz, 1998)

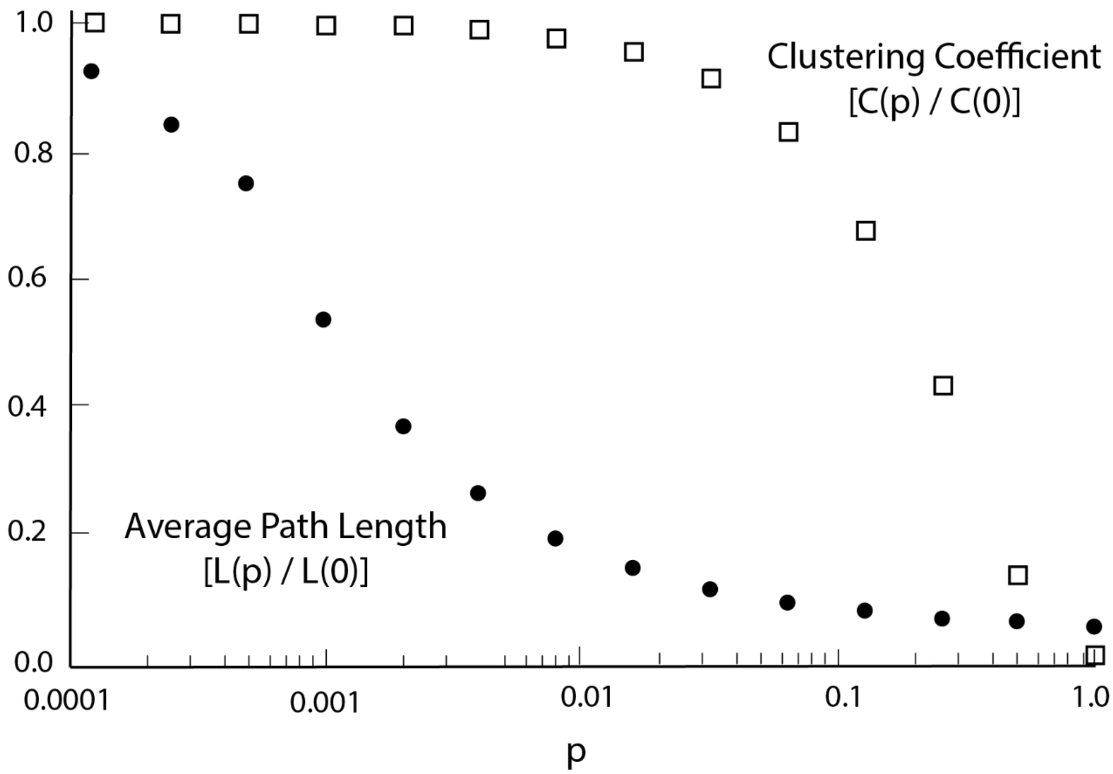


Figure 16: A Broad Range of Probabilities Yield a Short Path Length with High Clustering

(Source: Watts & Strogatz, 1998)

3.2.2.3 Diffusion Within a Complex Adaptive System

In a 2005 paper, Everett Rogers and his colleges (Rogers, Medina, Rivera, & Wiley, 2005) concluded that complex adaptive systems theory and the diffusion of innovation model could be used together as a predictive hybrid model of "induced change in population behaviour" (p.2). Although this makes sense, they seem to have continued with a normality assumption. While they discuss the power law distribution, and the scale-free property of power-law distributions, they failed to recognize that the cumulative distribution curve of a power law distribution is not an S-curve, stating that "A scale free network operates according to the power law. We will offer an example of scale-free network diffusion… The S-curve and other aggregate measures are depictions of such macro-level phenomena" (p.

13). Also, they did not test any data sets to see if they could statistically show if they were of a particular distribution type.

As noted in the introduction, the thesis of this paper is that the diffusion profile for each innovation is unique because it is the result of a complex adaptive system. There are many factors that affect the diffusion profile, including the five factors that Rogers (2003) identified: relative advantage, compatibility, complexity, triability, and observability. When these five factors are considered embedded within a small-world social network (the complex adaptive system), each innovation will encounter a unique set of circumstances that influences its adoption. The path that information about an innovation travels is unique for every innovation. As seen in Figure 16, a small change in the number of shortcuts results in a significant change in the average path length. In addition, network connections are constantly changing, and who each person communicates within their network varies from day to day. All of this leads to unpredictability in the resultant distribution curve.

3.2.3 Method

In order to determine if diffusion data might lend support to the hypothesis that the diffusion pattern of each innovation is random and unique, Canadian diffusion data for internet, cellphone, broadband internet, microwave oven, VCR, and home computer adoption was obtained from The World Bank's World Development Indicators dataset located at https://data.worldbank.org/data-catalog/world-development-indicators (see Appendix 1 for the six datasets and graphs of the data).

For analysis purposes, data were converted to relative years of diffusion, that is, the number of years since the product was first widely available. All data after the adoption percentage reached a maximum was truncated since the characteristic of interest is the diffusion of a new product, not the decline of a mature product. As a first approximation to see if the data might represent a power law (see, for example: Faloutsos, Faloutsos, & Faloutsos, 1999; Levy & Solomon, 1996), the data for each series was converted to a log-log format, and a linear regression was performed to determine the 'a' and 'k' parameters for a best-fit power law of form $f(x)=kx^n$. An R-squared value was calculated to test for a possible power law fit. The Kolmogorov-Smirnov test was used to perform goodness-of-fit tests for power-law distributions (following Clauset, Shalizi, and Newman, 2009). Statistical analysis software was also used to perform goodness of fit tests for other distribution types, including: normal, lognormal, 3-parameter lognormal, logistic, log-logistic, 3-parameter logistic, gamma, 3-parameter gamma, smallest extreme value, largest extreme value, Weibull, 3-parameter Weibull, exponential, and 2-parameter exponential.

3.2.4 Results

An initial test for a power law distribution test was performed by converting the data to a log-log plot and testing for a straight line – see. The R^2 values were 0.99 for cellphones, 0.95 for home computers, 0.95 for broadband, 0.93 for internet, 0.87 for VCR and 0.81 for microwaves[50]. That is, the log of the data is a good fit to a straight line, warranting further investigation.

Each of the data sets was analyzed using the *power law Python package* developed by Alstott, Bullmore, and Plenz (2014). In each case, the Kolmogorov-Smirnov goodness of fit test suggests it is unlikely that the data is from a power-law distribution (see Appendix 2 for

[50] R-squared values are measures of how close the data points fit the regression line. 1.0 indicates a perfect fit.

the Python script used and the output). That is, at a significance level of $\alpha = 0.10$, the null hypothesis – that the data sets are power-law distributed – is rejected for each of the six data sets.

Using a statistical analysis software package gave the same result when testing for other distribution types, indicating the null hypothesis must be rejected at the $\alpha = 0.10$ significance level. That is, at a 90% or higher probability level, the data is not from any common distribution type. (See Appendix 3 for the output from the statistical package and a complete list of the 16 distribution types tested.)

3.2.5 Conclusions and Future Research

There has been, in recent years, been considerable research showing that many social, technological, and natural phenomenon follow power-law distributions rather than normal distributions (Goldstein, Morris, & Yen, 2004). Power law distributions, and their characteristic extreme events, occur because of the feedback loops, self-organization, and network effects that occur in complex adaptive systems (Clauset, 2011). However, there is still a bias toward research and analysis that assumes normal distributions, which rules out the extremes of power-law distributions (Andriani & McKelvey, 2007). This bias influences theory development, research agendas, and practical applications in every area where the normality assumption exists. According to Andriani and McKelvey (2007), "The cost is inaccurate science and irrelevance to practitioners" (p. 1212). This conclusion also applies to areas where the data does not fit any particular distribution type.

The widespread occurrence of power laws in complex adaptive systems (Fang, Wang, Liu, & Gong, 2012), might lead one to expect to see a power law distribution in diffusion-of-innovation data. Indeed, the initial test for a power law distribution – a straight line when converted to a log-log plot (Levy & Solomon, 1996) – was positive for the six datasets analyzed, as indicated in the previous section. However, Clauset, Shalizi, and Newman (2009) and Goldstein et al. (2004), argue that the straight-line on a log-log plot is not a sufficiently robust test, resulting in too many false positives.

Should we expect diffusion data to follow any common distribution type? If the diffusion of innovations is a social process, as Rogers (2003) argues, and occurs through small-world social networks (Easley & Kleinberg, 2010), which are complex adaptive systems (Amaral, Scala, Barthelemy, & Stanley, 2000), then the diffusion of innovations occurs as part of a complex adaptive system. In complex adaptive systems, we should expect randomness from individual agents, while patterns emerge at higher levels, that is, with aggregate data (such as the box office receipts graphed in Figure 12: Box Office Receipts. Indeed, this study found that the data for the diffusion of individual innovations does not fit a power law distribution or any of the 16 other common distributions tested for.

The diffusion data analyzed here supports the concept of complexity theory as a model for creativity since the data has no discernable pattern. It seems more likely that patterns will emerge with aggregated data, rather than looking at the journey of individual innovations. For example, De Vany (2006) has indicated that movie box office receipts follow a power law, but the result of any one release remains unpredictable. A quick look at other aggregate diffusion of innovation data (for example – the results of crowd-funding campaigns) looks as though it may also follow a power law. Further research in this area would help us better understand the behaviour of complex adaptive systems in general and would help us better understand the diffusion of innovations specifically.

Of course, these conclusions should be confirmed by performing a similar analysis with more data sets covering different geographies, different types of innovations, and different diffusion modalities. For example, diffusion data from online crowd-funding campaigns may provide large data sets that would help improve the accuracy of such an analysis. One of the limitations of the current analysis is the relatively small number of data points for each data set, which ranges from 17 to 31. Due to the nature of power-law distributions – significant clustering of data towards one end of the distribution and a small number of results far out in the tail – large data sets are less likely to give a false negative result. As stated by Clauset et al.:

> Unfortunately, the detection and characterization of power laws is complicated by the large fluctuations that occur in the tail of the distribution -- the part of the distribution representing large but rare events -- and by the difficulty of identifying the range over which power-law behavior holds" (2009, p. 1).

Everett Rogers and his colleagues (2005), discuss the similarities between the diffusion of innovation model and complex adaptive systems theory. However, they stop short of directly saying the diffusion of innovations is the result of – the emergent behaviour of – a complex adaptive system. This is surprising, given that social networks are generally recognized as complex adaptative systems (Easley & Kleinberg, 2010) and Rogers has long recognized that the diffusion of innovations is a social process that propagates through a social network (Rogers, 1962).

As far back as 1943, Ryan & Gross (1943) noted, regarding their diffusion of hybrid seed data: "Obviously any reference to the observed distribution as a normal one would be quite misleading" (p. 23). They concluded that "formulation of ideal diffusion curves must wait upon analysis of vastly more material than has yet been done, but it seems doubtful if any theoretic pattern can adequately conform to situations involving all degrees of interaction and isolation" (p. 24). Seventy-five years later, this study reaches the same conclusion. While the data required may already exist, it has yet to be analyzed in a way that would answer the questions: Does the diffusion of innovations, in general, conform to a distribution type? If not, do certain types of diffusion conform to one distribution type, while others conform to another type? What are the factors that determine different distributions types, if any?

On the other hand, a review of the literature – diffusion of innovation, complexity theory, and small-world networks – suggests (see section 2) that these are the results we should expect. The diffusion parameters are so numerous and varied that we should expect each diffusion pattern to be unique. Rogers (2003) correctly identified these parameters as communication channels, the social system, relative advantage, compatibility, complexity, triability, and observability. In addition, when the social system is viewed as a small-world network, clustering, path-length, and strength of ties add to the complexity of diffusion networks, resulting in each instance being unique.

However, just as we cannot predict the success of an individual movie release, patterns arise in the aggregate. That is, when the diffusion data of many innovations are aggregated, we can expect to see a power law distribution – as seen in the box office data shown in Figure 12: Box Office Receipts.

As stated earlier, this work should be extended to further products and different geographies to confirm the hypothesis that the diffusion data of any individual innovation does not consistently follow a common distribution type. Of particular interest is the diffusion of crowd-funded products and non-physical products such as apps and other software, where rapid adoption rates are often observed. A comparison of products that require a critical mass due to network effects (for example, Twitter and Facebook), versus those that don't would add to our understanding of diffusion characteristics, as would a comparison across Rogers' five innovation characteristics that influence the rate of adoption. It is anticipated that, in each case, the result will be the same – no consistent distribution types, unless the small-world network parameters can also be controlled for. However, aggregations of the data are expected to reveal power law distributions.

What does all this mean to the individual or organization trying to get their innovations adopted? The main lessons to take away from this are: 1) Focus on small clusters, then use their weak ties to create beachheads in other clusters. 2) Use a variety of approaches with multiple starting points and times. These points relate to the lean startup methodology pioneered by Steve Blank (Blank & Dorf, 2012) and Eric Ries (Ries, 2011), although the relationship may not be immediately apparent. Both the lean start-up methodology and the conclusions of this paper are that those wishing to have an innovation diffuse broadly must proceed in small incremental steps. Lean start-up methodology suggests this approach in order to make sure the innovation is one that people truly want. The complex adaptive systems view of the diffusion of innovations concludes this is the case because you can never be sure what will work – there is always a degree of uncertainty.

Bibliography

Aaron Clauset. (2011). *Inference, Models and Simulation for Complex Systems* (No. Lecture 2). Retrieved from http://tuvalu.santafe.edu/~aaronc/courses/7000/csci7000-001_2011_L2.pdf

Alstott, J., Bullmore, E., & Plenz, D. (2014). powerlaw: a Python package for analysis of heavy-tailed distributions. Retrieved June 30, 2018, from https://arxiv.org/pdf/1305.0215.pdf

Amaral, L. A. N., Scala, A., Barthelemy, M., & Stanley, H. E. (2000). Classes of small-world networks. *Proceedings of the National Academy of Sciences of the United States of America*, *97*(21), 11149–11152.

Andriani, P., & McKelvey, B. (2007). Beyond Gaussian averages: redirecting international business and management research toward extreme events and power laws. *Journal of International Business Studies*, *38*(7), 1212.

Blank, S., & Dorf, B. (2012). *The Startup Owner's Manual: The Step-by-Step Guide for Building a Great Company*. BookBaby.

Brynjolfsson, E. (1993). The Productivity Paradox of Information Technology. *Commun. ACM*, *36*(12), 66–77. https://doi.org/10.1145/163298.163309

Carson, S. (2010). *Your creative brain: Seven steps to maximize imagination, productivity, and innovation in your life*. San Francisco, CA: Wiley.

Christensen, C. M. (1992). Exploring the Limits of the Technology S-Curve. Part I: Component Technologies. *Production and Operations Management*, *1*(4), 334–357. https://doi.org/10.1111/j.1937-5956.1992.tb00001.x

Christensen, C. M. (1997). *The innovator's dilemma: When new technologies cause great firms to fail.*

Boston, MA: Harvard Business Review Press.

Clauset, A., Shalizi, C. R., & Newman, M. E. J. (2009). Power-Law Distributions in Empirical Data. *Siamreview SIAM Review*, *51*(4), 661–703.

David, P. A. (1990). The Dynamo And The Computer: An Historical Perspective On T. *The American Economic Review*, *80*(2), 355.

De Vany, A. (2006). The Movies. In V. A. Ginsburgh & D. Throsby (Eds.), *Handbook of the Economics of Art and Culture*. Boston, MA: Elsevier.

Downes, L., & Nunes, P. (2013). Big-bang disruption. *Harvard Business Review*, (March). Retrieved from https://hbr.org/2013/03/big-bang-disruption/

Downes, L., & Nunes, P. (2014). *Big Bang Disruption: Business Survival in the Age of Constant Innovation*. New York, NY: Penguin Books Limited.

Easley, D., & Kleinberg, J. (2010). *Networks, crowds, and markets : reasoning about a highly connected world*. New York: Cambridge University Press.

Faloutsos, M., Faloutsos, P., & Faloutsos, C. (1999). On power-law relationships of the Internet topology. *SIGCOMM Comput. Commun. Rev. ACM SIGCOMM Computer Communication Review*, *29*(4), 251–262.

Fang, Z., Wang, J., Liu, B., & Gong, W. (2012). Double Pareto Lognormal Distributions in Complex Networks BT - Handbook of Optimization in Complex Networks: Theory and Applications. In M. T. Thai & P. M. Pardalos (Eds.), *Handbook of Optimization in Complex Networks* (pp. 55–80). Boston, MA: Springer US. https://doi.org/10.1007/978-1-4614-0754-6_3

Goldman, W. (1983). *Adventures in the screen trade: A personal view of Hollywood and screenwriting.* New York: Warner Books.

Goldstein, M. L., Morris, S. A., & Yen, G. G. (2004). Problems with fitting to the power-law distribution. *Eur. Phys. J. B The European Physical Journal B - Condensed Matter and Complex Systems*, *41*(2), 255–258.

Henderson, R. (1995). Of life cycles real and imaginary: The unexpectedly long old age of optical lithography. *Research Policy*, *24*(4), 631.

Levy, M., & Solomon, S. (1996). Power Laws are Logarithmic Botlzmann Laws. *International Journal of Modern Physics C*, *07*(04), 595–601. https://doi.org/10.1142/S0129183196000491

Lobo, I. (2008). Biological complexity and integrative levels of organization. https://doi.org/10.1126/science.101.2618.209

Milgram, S. (1967). The Small World Problem. *Psychology Today*, *1*(1), 61–67. Retrieved from http://snap.stanford.edu/class/cs224w-readings/milgram67smallworld.pdf

Montoya, J., & Sol, R. (2002). Small world patterns in food webs. *Journal of Theoretical Biology*, *214*(3), 405–412.

Moore, G. A. (2014). *Crossing the Chasm: Marketing and Selling Disruptive Products to Mainstream Customers* (3rd ed.). New York, NY: HarperCollins.

Page, S. E. (2009). *Understanding complexity*. Chantilly, Va.: Teaching Company.

Ries, E. (2011). *The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses*. Crown Business. Retrieved from https://books.google.ca/books?id=r9x-OXdzpPcC

Robinson, K. (2011). *Out of Our Minds: Learning to be Creative*. Chichester, UK: Capstone Publishing Ltd.

Rogers, E. M. (1962). *Diffusion of Innovations*. Free Press of Glencoe. Retrieved from https://books.google.ca/books?id=XAY-AAAAIAAJ

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). New York, NY: Free Press.

Rogers, E. M., Medina, U. E., Rivera, M. a, & Wiley, C. J. (2005). Complex Adaptive Systems and The Diffusion of Innovations. *The Innovation Journal: The Public Sector Innovation Journal*, *10*(3), 1–26.

Ryan, B., & Gross, N. (1943). The diffusion of hybrid seed corn in two Iowa communities. *Rural Sociology*, *8*(1), 15–24. Retrieved from http://chla.library.cornell.edu/cgi/t/text/pageviewer-idx?c=chla;rgn=full text;idno=5075626_4294_001;view=image;seq=17

Ryan, B., & Gross, N. c. (1950). *Acceptance and Diffusion of Hybrid Corn Seed in Two Iowa Communities*. Agricultural Experiment Station, Iowa State College of Agriculture and Mechanic Arts. Retrieved from http://lib.dr.iastate.edu/researchbulletin/vol29/iss372/1/

Snow, D. C. (2004). Extraordinary efficiency growth in response to new technology entries: The carburetor's "last gasp." *Academy of Management Proceedings*.

Snow, D. C. (2008). Beware of old technologies' last gasps. *Harvard Business Review*, *86*(1), 17–18. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=27996045&site=ehost-live&scope=site

Tarde, G., & Parsons, E. C. (1903). *The Laws of Imitation*. Rahway, NJ: H. Holt. Retrieved from https://archive.org/details/lawsofimitation00tard

Travers, J., & Milgram, S. (1969). An Experimental Study of the Small World Problem. *Sociometry*, *32*(4), 425.

Wadhwa, V. (2012). Innovation without Age Limits. *MIT Technology Review*, *February*. Retrieved from https://www.technologyreview.com/s/426760/innovation-without-age-limits/

Watts, D. J. (1999). *Small Worlds: The Dynamics of Networks Between Order and Randomness*. Princeton, NJ: Princeton University Press.

Watts, D. J. (2004). The "New" Science of Networks. *Annual Review of Sociology*, *30*(1), 243–270. https://doi.org/10.1146/annurev.soc.30.020404.104342

Watts, D. J., & Strogatz, S. H. (1998). Collective dynamics of "small-world" networks. *Nature*, *393*(6684), 440–442.

Appendix 1: Raw Data and Graphs

Table 2: Percentage Adoption Rates by Years Since Introduced

Years	Internet	Cellphone	Broadband	Microwaves	VCR	Home Computer
31		82.98				
30		81.04				
29		80.61				
28		79.57				84.50
27		77.83				84.30
26	88.47	75.68		94.20		85.40
25	87.12	70.55		94.40		84.00
24	85.80	66.20		93.50		84.30
23	83.00	61.47		93.90		81.70
22	83.00	57.49		94.10		79.40
21	80.30	52.76		93.80		78.40
20	80.30	47.06		93.00		75.40
19	76.70	42.07		92.40		72.00
18	73.20	37.95	36.32	91.30		68.70
17	72.40	34.37	35.38	90.80	92.10	66.60
16	71.66	28.43	34.38	89.60	91.60	64.10
15	65.96	22.72	33.56	88.70	89.90	59.80
14	64.20	17.74	32.72	88.10	88.70	55.20
13	61.59	14.05	31.70	85.30	88.00	50.00
12	60.20	11.82	30.49	83.40	87.20	45.20
11	51.30	8.84	29.49	81.10	83.50	39.80
10	36.19	6.44	27.51	78.80	82.10	31.60
9	24.90	4.65	24.67	75.60	79.20	28.80
8	15.07	3.62	21.72	73.30	77.30	25.00
7	6.76	2.77	16.97	68.20	73.60	23.20
6	4.16	2.11	14.29	42.90	68.50	20.00
5	2.38	1.26	11.24	33.40	66.20	18.50
4	1.18	0.75	9.15	22.70	45.10	16.20
3	0.92	0.37	4.60	12.44	35.20	12.95
2	0.57	0.23	1.91	10.20	23.40	10.30
1	0.36	0.05	0.46	0.78	6.43	10.30

Figure 17: Diffusion of Innovation in Canada – Non-cumulative Distributions

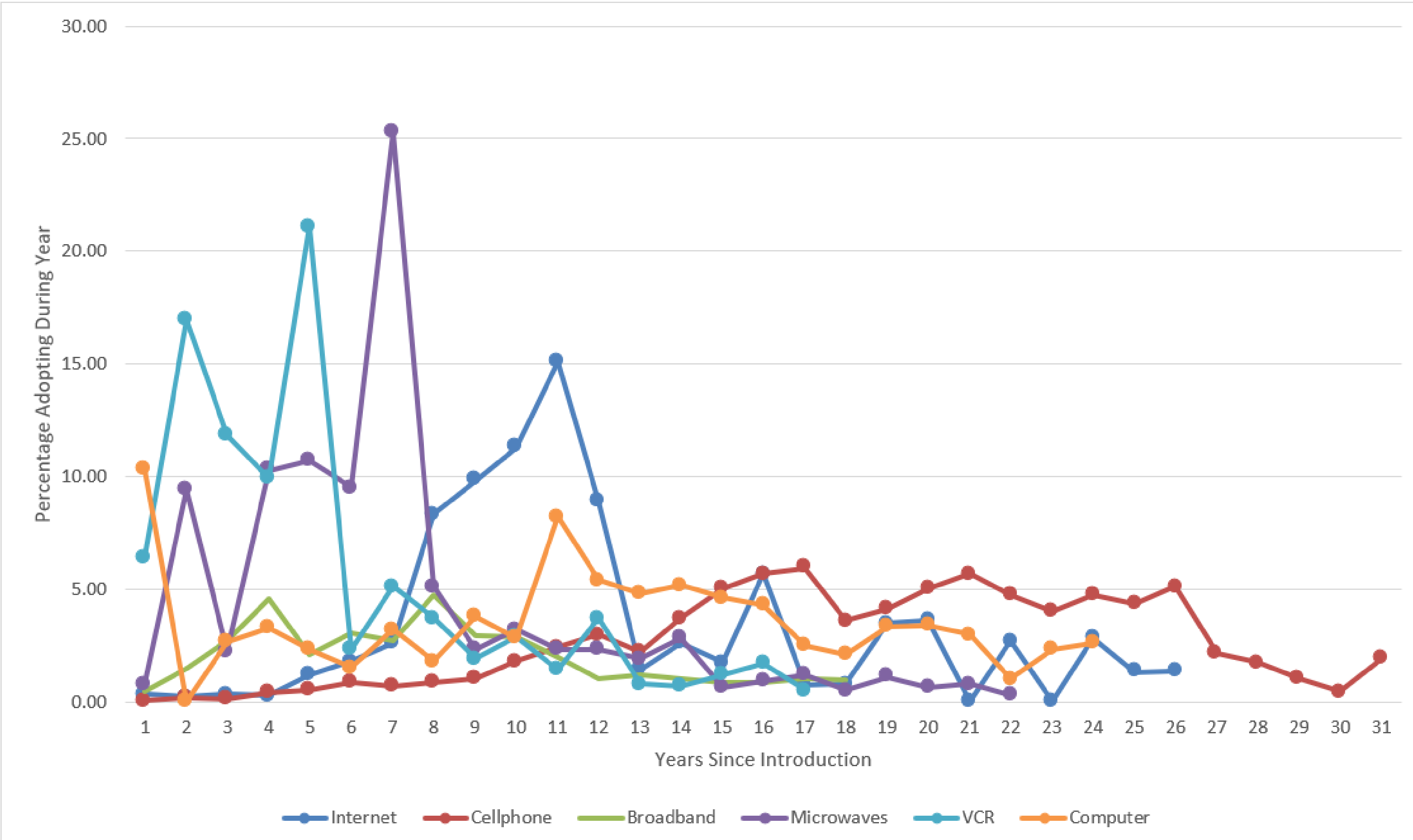


Figure 18: Diffusion of Innovation in Canada – Cumulative Distribution

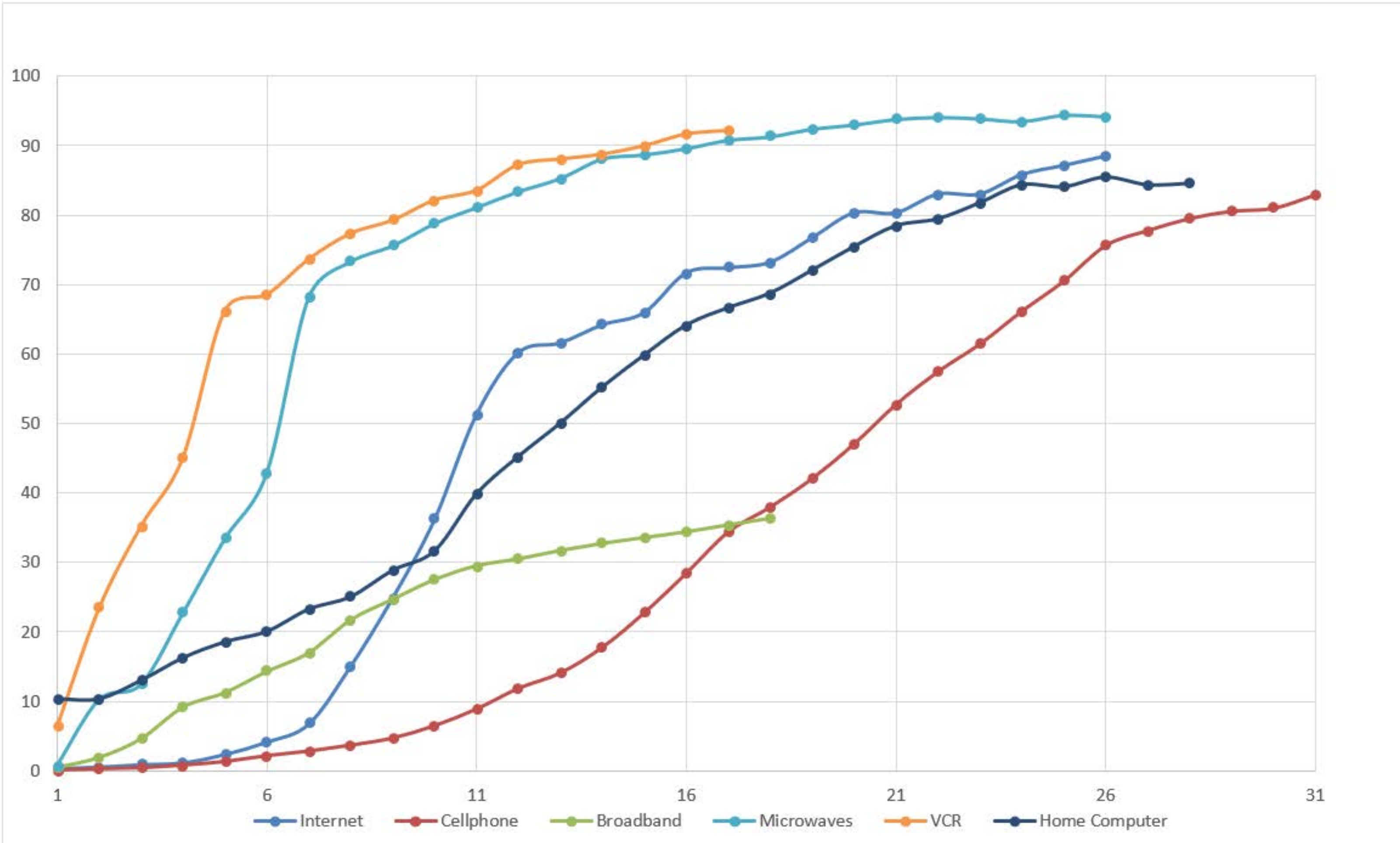


Figure 19: Log-Log Product Diffusion in Canada

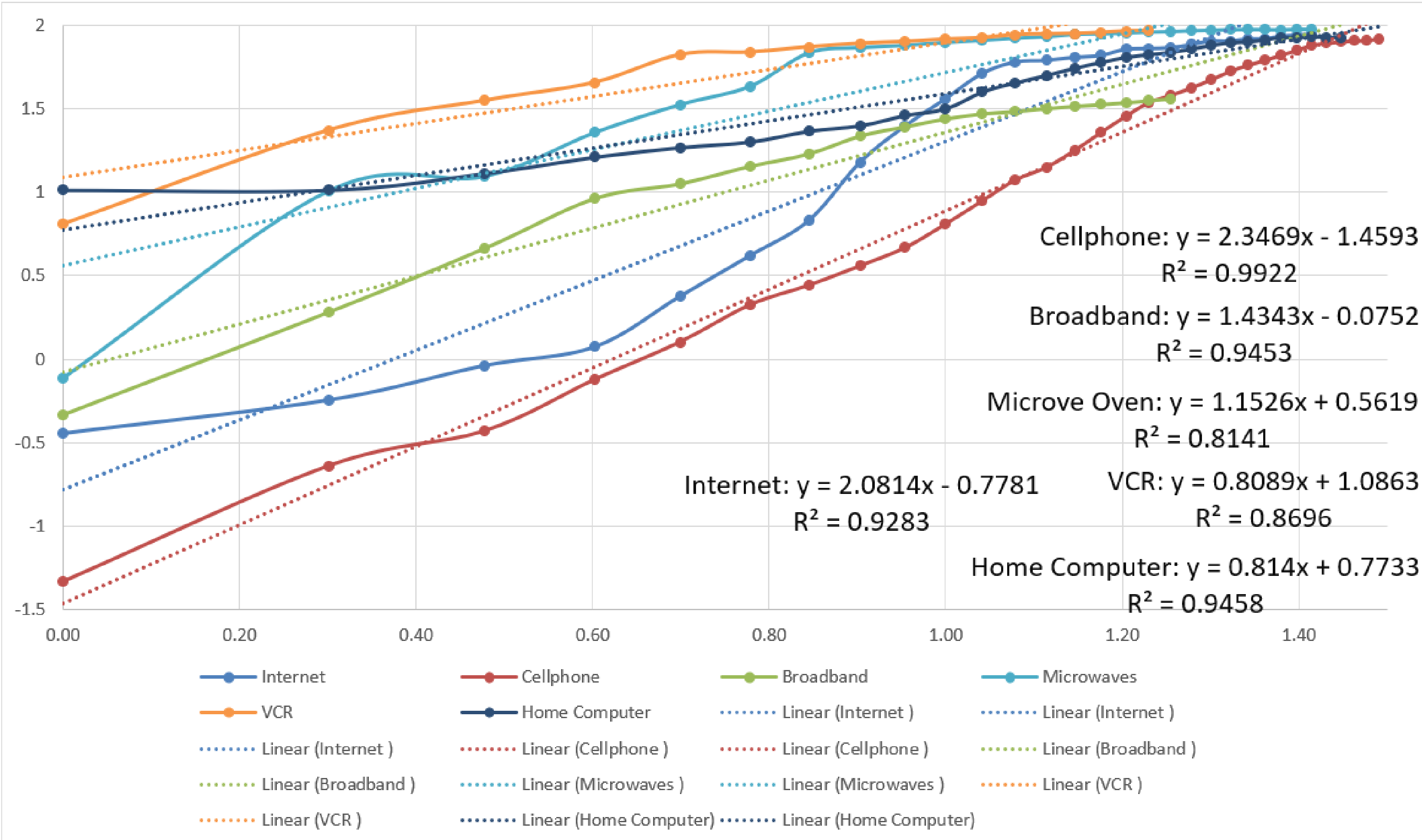


Figure 20: Actual versus Predicted Values

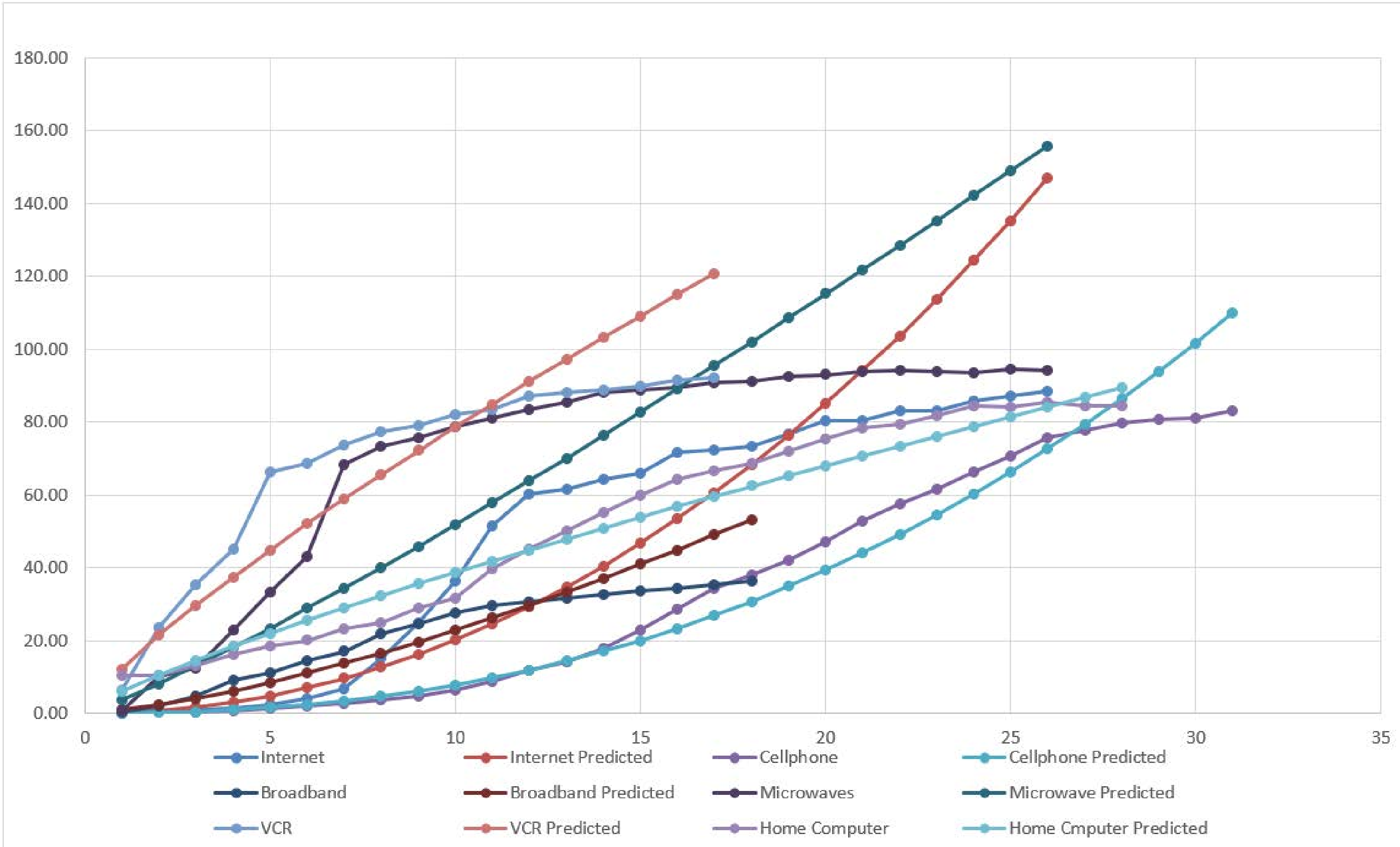
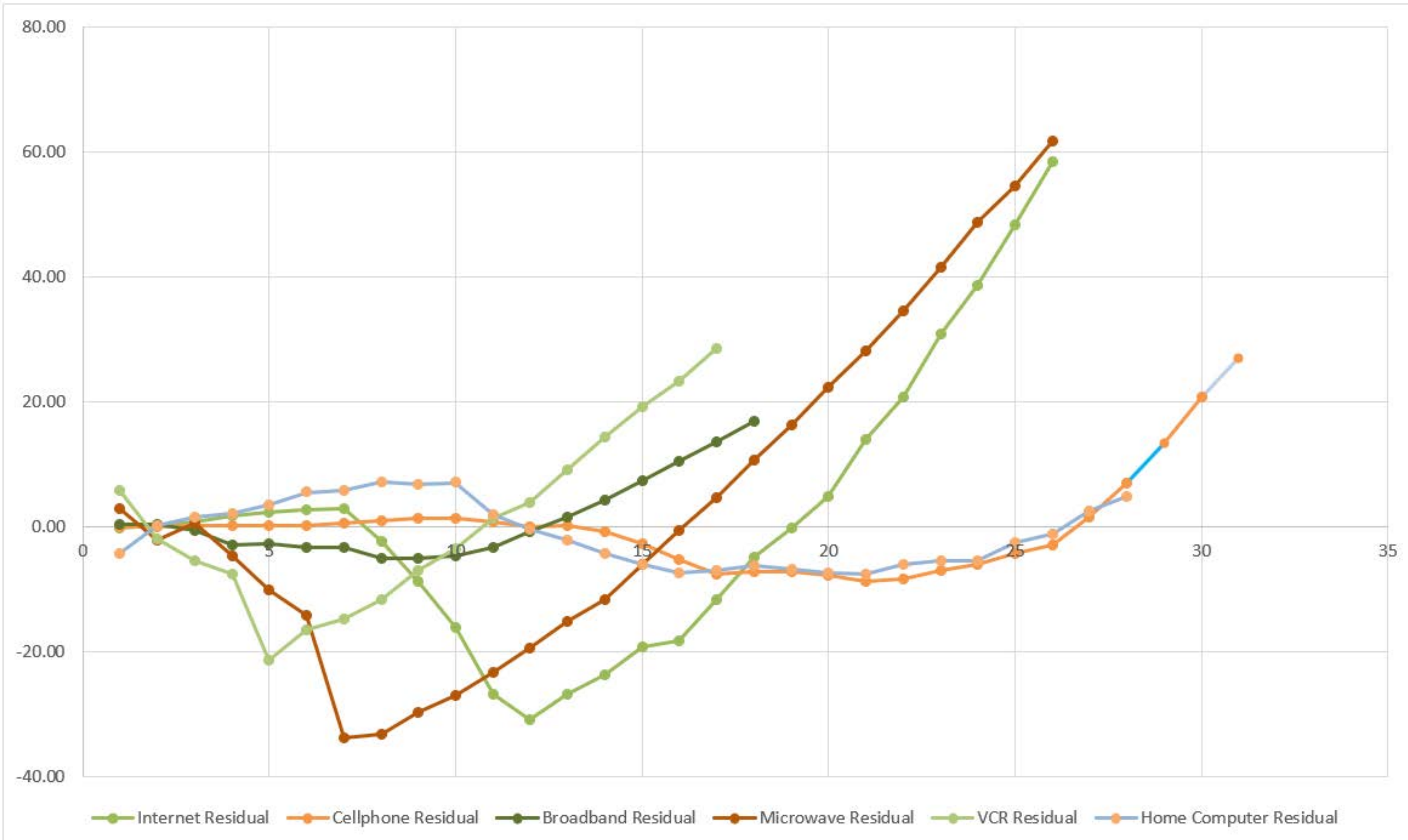


Figure 21: Residuals



Appendix 2: Python Powerlaw Analysis Scripts and Results

Internet

```
import powerlaw as pl
import numpy as np
import mpmath
import matplotlib
import scipy
np.seterr(divide='ignore', invalid='ignore')
internet = np.genfromtxt ('C:\\temp\\data\\internet.txt', delimiter=",",
dtype=(int))
print ('Internet data:',internet)
results=pl.Fit(internet)
print('Alpha for internet data = ',results.power_law.alpha)
print('Xmin for internet data = ',results.power_law.xmin)
R, p = results.distribution_compare('power_law', 'lognormal')
print ('Internet data R and p for Power Law: Lognormal compare =',R, p)
print ('Likelihoods',results.power_law.likelihoods(internet))
print ('KS', results.power_law.KS(internet))
```

Output:

```
Internet data: [ 2  2  2 ..., 26 26 26]
Alpha for internet data =  3.29498187255
Xmin for internet data =  9.0
Calculating best minimal value for power law fit
Internet data R and p for Power Law: Lognormal compare = -1143.1274611
1.30825278954e-195
Likelihoods [ 0.25499799  0.25499799  0.25499799 ...,  0.00773458  0.00773458
  0.00773458]
KS 0.130288480562
```

Cellphone

```
import powerlaw as pl
```

```
import numpy as np
import mpmath
import matplotlib
import scipy
np.seterr(divide='ignore', invalid='ignore')
cellphone = np.genfromtxt ('C:\\temp\\data\\cellphone.txt', delimiter=",",
dtype=(int))
print ('Cellphone data:',cellphone)
results=pl.Fit(cellphone)
print('Alpha for cellphone data = ',results.power_law.alpha)
print('Xmin for cellphone data = ',results.power_law.xmin)
R, p = results.distribution_compare('power_law', 'lognormal')
print ('Cellphone data R and p for Power Law: Lognormal compare =',R, p)
print ('Likelihoods',results.power_law.likelihoods(cellphone))
print ('KS', results.power_law.KS(cellphone))
```

Output:

```
Cellphone data: [ 1  1  1 ..., 31 31 31]
Alpha for cellphone data =  12.9395100182
Xmin for cellphone data =  25.0
Cellphone data R and p for Power Law: Lognormal compare = -96.6573953826
2.66546523904e-17
Likelihoods [ 0.4775804   0.4775804   0.4775804  ...,  0.02952675  0.02952675
  0.02952675]
KS 0.151927389628
Calculating best minimal value for power law fit
```

<u>Broadband</u>

```
import powerlaw as pl
import numpy as np
import mpmath
import matplotlib
import scipy
```

```
np.seterr(divide='ignore', invalid='ignore')
broadband= np.genfromtxt ('C:\\temp\\data\\broadband.txt', delimiter=",",
dtype=(int))
print ('Broadband data:',broadband)
results=pl.Fit(broadband)
print('Alpha for broadband data = ',results.power_law.alpha)
print('Xmin for broadband data = ',results.power_law.xmin)
R, p = results.distribution_compare('power_law', 'lognormal')
print ('Broadband data R and p for Power Law: Lognormal compare =',R, p)
print ('Likelihoods',results.power_law.likelihoods(broadband))
print ('KS', results.power_law.KS(broadband))
```

Output:

```
Broadband data: [ 1  1  1 ..., 18 18 18]
Alpha for broadband data =  3.95525393147
Xmin for broadband data =  8.0
Broadband data R and p for Power Law: Lognormal compare = -233.501278027
6.91100523232e-34
Likelihoods [ 0.36940674  0.36940674  0.36940674 ...,  0.01494629  0.01494629
  0.01494629]
KS 0.138733688068
Calculating best minimal value for power law fit
```

<u>Microwave</u>

```
import powerlaw as pl
import numpy as np
import mpmath
import matplotlib
import scipy
np.seterr(divide='ignore', invalid='ignore')
microwave= np.genfromtxt ('C:\\temp\\data\\microwave.txt', delimiter=",",
dtype=(int))
print ('Microwave data:',microwave)
```

```
results=pl.Fit(microwave)
print('Alpha for microwave data = ',results.power_law.alpha)
print('Xmin for microwave data = ',results.power_law.xmin)
R, p = results.distribution_compare('power_law', 'lognormal')
print ('Microwave data R and p for Power Law: Lognormal compare =',R, p)
print ('Likelihoods',results.power_law.likelihoods(microwave))
print ('KS', results.power_law.KS(microwave))
```

Output:

```
Microwave data: [ 1  1  1 ..., 26 26 26]
Alpha for microwave data =  3.31944019896
Xmin for microwave data =  7.0
Calculating best minimal value for power law fit
Microwave data R and p for Power Law: Lognormal compare = 0.239390464276
0.0549567561028
Likelihoods [ 0.3313486   0.3313486   0.3313486  ...,  0.00425224  0.00425224
  0.00425224]
KS 0.126190805725
```

VCR

```
import powerlaw as pl
import numpy as np
import mpmath
import matplotlib
import scipy
np.seterr(divide='ignore', invalid='ignore')
vcr= np.genfromtxt ('C:\\temp\\data\\vcr.txt', delimiter=",", dtype=(int))
print ('VCR data:',vcr)
results=pl.Fit(vcr)
print('Alpha for VCR data = ',results.power_law.alpha)
print('Xmin for VCR data = ',results.power_law.xmin)
R, p = results.distribution_compare('power_law', 'lognormal')
print ('VCR data R and p for Power Law: Lognormal compare =',R, p)
```

```
print ('Likelihoods',results.power_law.likelihoods(vcr))
print ('KS', results.power_law.KS(vcr))
```

Output:

VCR data: [1 1 1 ..., 17 17 17]

Alpha for VCR data = 3.25572906585

Xmin for VCR data = 5.0

Calculating best minimal value for power law fit

VCR data R and p for Power Law: Lognormal compare = -25.5532709034 7.20481519988e-05

Likelihoods [0.45114581 0.45114581 0.45114581 ..., 0.00839393 0.00839393 0.00839393]

KS 0.146958503385

Home Computer

```
import powerlaw as pl
import numpy as np
import mpmath
import matplotlib
import scipy
np.seterr(divide='ignore', invalid='ignore')
homecomputer= np.genfromtxt ('C:\\temp\\data\\Homecomputer.txt', delimiter=",", dtype=(int))
print ('Home computer data:',homecomputer)
results=pl.Fit(homecomputer)
print('Alpha for Home computer data = ',results.power_law.alpha)
print('Xmin for Home computer data = ',results.power_law.xmin)
R, p = results.distribution_compare('power_law', 'lognormal')
print ('Homecomputer data R and p for Power Law: Lognormal compare =',R, p)
print ('Likelihoods',results.power_law.likelihoods(homecomputer))
print ('KS', results.power_law.KS(homecomputer))
```

Output:

Home computer data: [1 1 1 ..., 25 25 25]

Alpha for Home computer data = 3.87309377146

Xmin for Home computer data = 12.0

Calculating best minimal value for power law fit

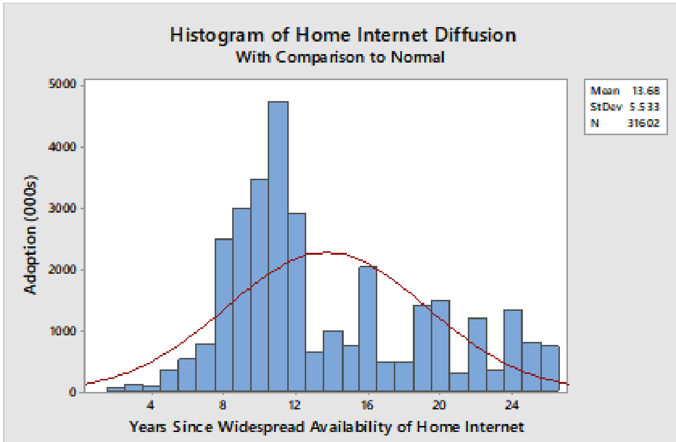
Homecomputer data R and p for Power Law: Lognormal compare = -1976.80964456 4.37160552219e-271

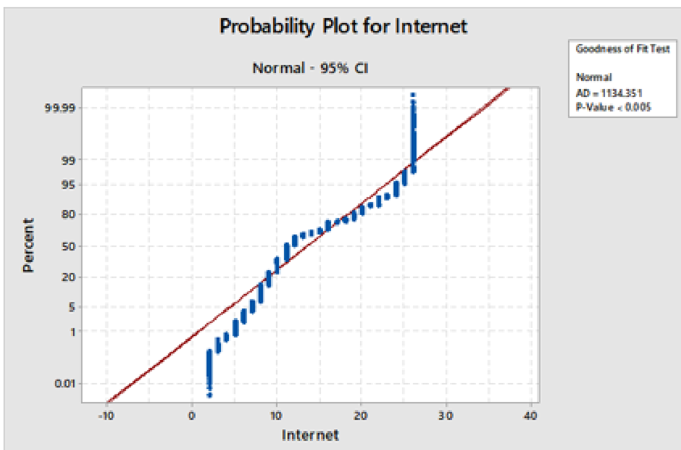
Likelihoods [0.23942448 0.23942448 0.23942448 ..., 0.01395038 0.01395038 0.01395038]

KS 0.171471592128

Appendix 3: Minitab Results: Test for Normal Distribution[51]

Internet





Descriptive Statistics

N	N*	Mean	StDev	Median	Minimum	Maximum	Skewness	Kurtosis
1602	0	13.6769	5.53288	12	2	26	0.696723	-0.578926

Goodness of Fit Test

Distribution	AD	P
Normal	1134.351	<0.005

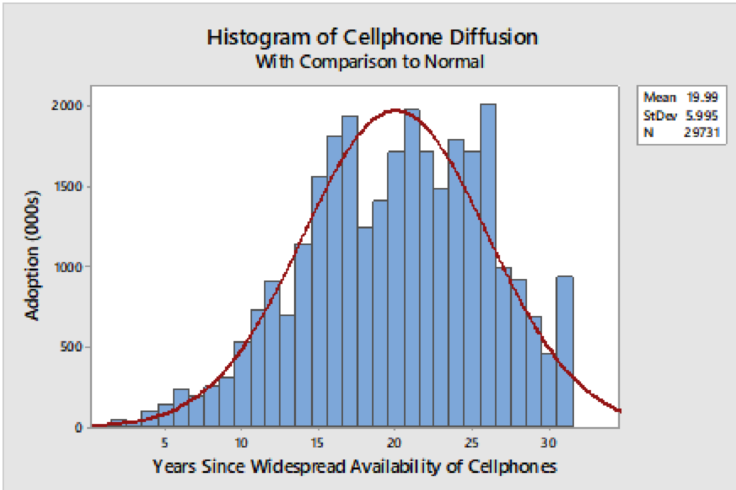
ML Estimates of Distribution Parameters

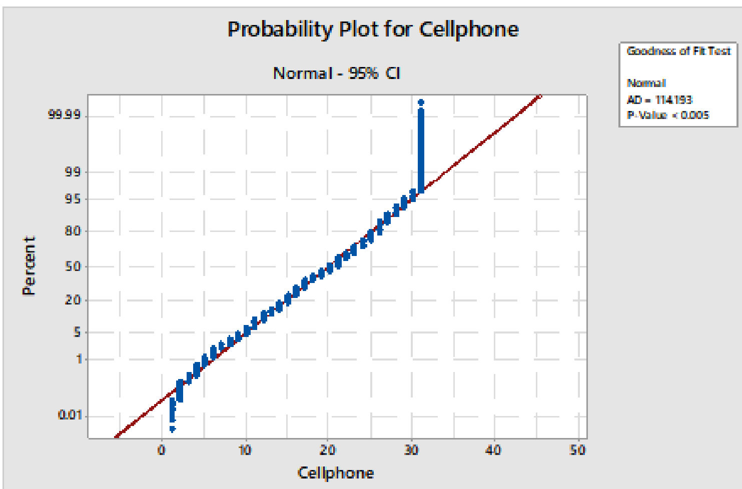
Distribution	Location	Shape	Scale	Threshold
Normal*	13.67692		5.53288	

** Scale: Adjusted ML estimate*

[51] For all plots, the horizontal 'x' axis represents the years since the indicated product was first widely available.

Cellphone





Descriptive Statistics

N	N*	Mean	StDev	Median	Minimum	Maximum	Skewness	Kurtosis
29731	0	19.9878	5.99459	20	1	31	-0.295103	-0.397139

Goodness of Fit Test

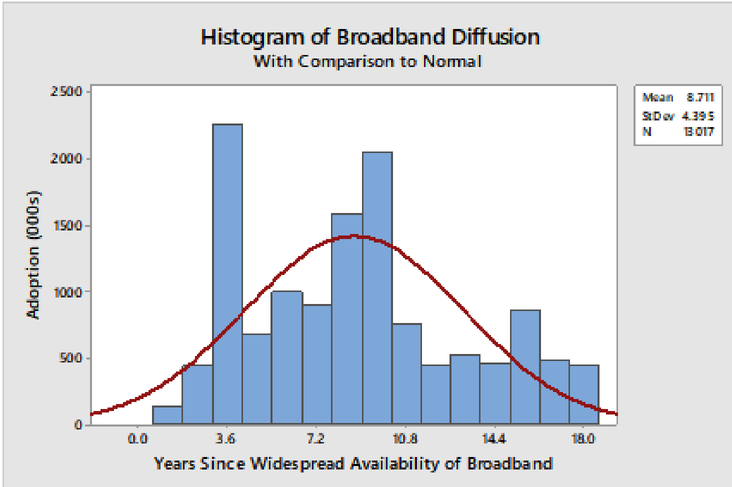
Distribution	AD	P
Normal	114.193	<0.005

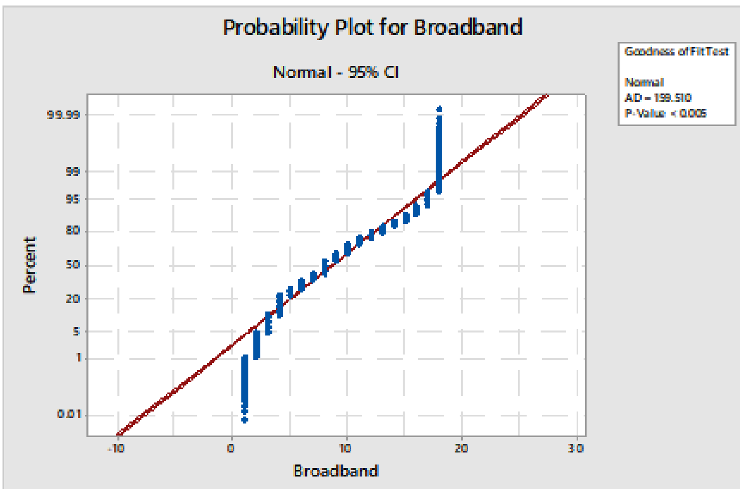
ML Estimates of Distribution Parameters

Distribution	Location	Shape	Scale	Threshold
Normal*	19.98776		5.99459	

** Scale: Adjusted ML estimate*

Broadband





Descriptive Statistics

N	N*	Mean	StDev	Median	Minimum	Maximum	Skewness	Kurtosis
13017	0	8.71084	4.39484	8	1	18	0.433508	-0.681781

Goodness of Fit Test

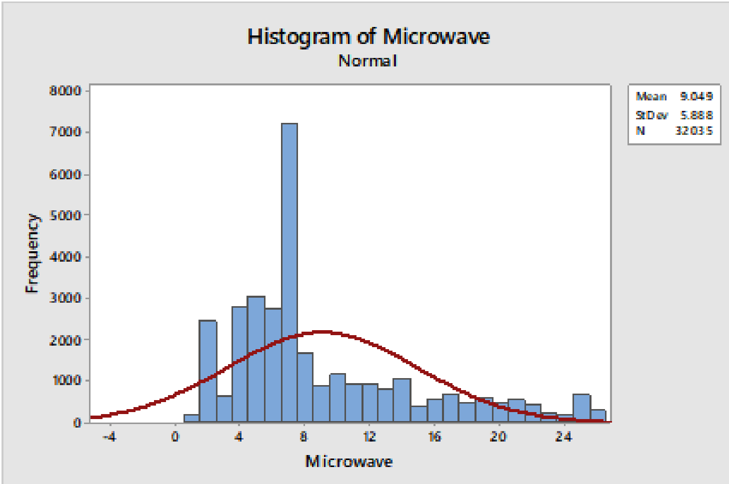
Distribution	AD	P
Normal	159.510	<0.005

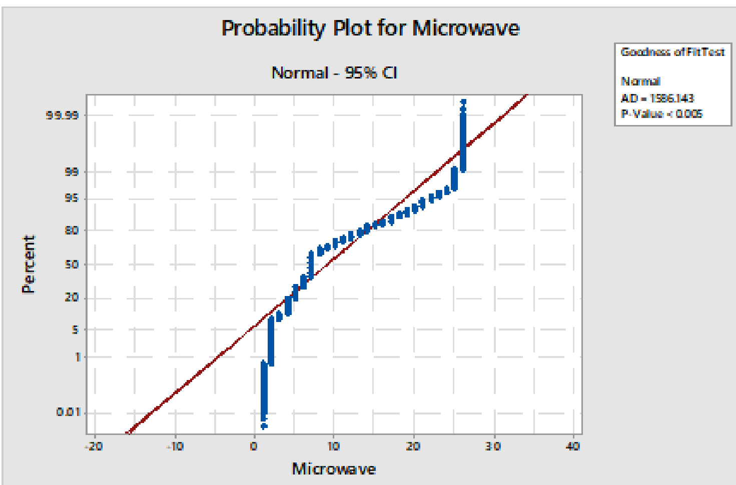
ML Estimates of Distribution Parameters

Distribution	Location	Shape	Scale	Threshold
Normal*	8.71084		4.39484	

** Scale: Adjusted ML estimate*

Microwave





Descriptive Statistics

N	N*	Mean	StDev	Median	Minimum	Maximum	Skewness	Kurtosis
32035	0	9.04892	5.88787	7	1	26	1.18452	0.629356

Goodness of Fit Test

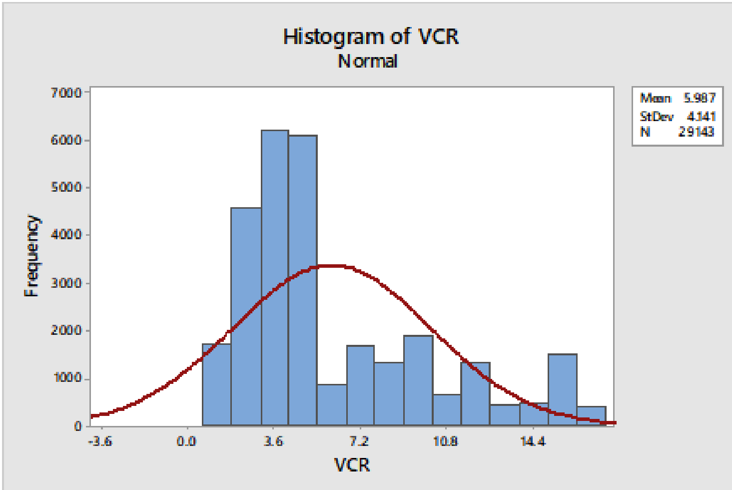
Distribution	AD	P
Normal	1586.143	<0.005

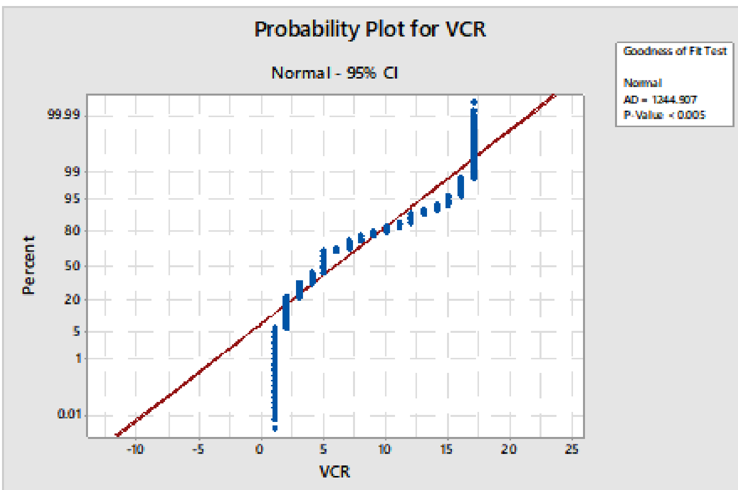
ML Estimates of Distribution Parameters

Distribution	Location	Shape	Scale	Threshold
Normal*	9.04892		5.88787	

** Scale: Adjusted ML estimate*

VCR





Descriptive Statistics

N	N*	Mean	StDev	Median	Minimum	Maximum	Skewness	Kurtosis
29143	0	5.98686	4.14104	5	1	17	1.03634	0.156678

Goodness of Fit Test

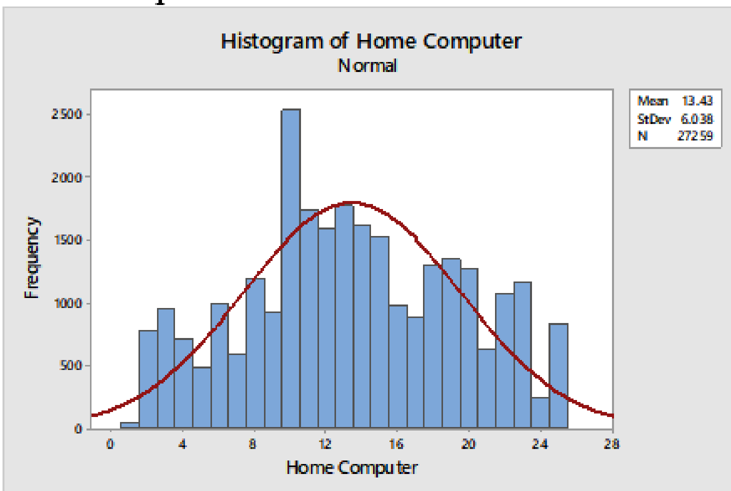
Distribution	AD	P
Normal	1244.907	<0.005

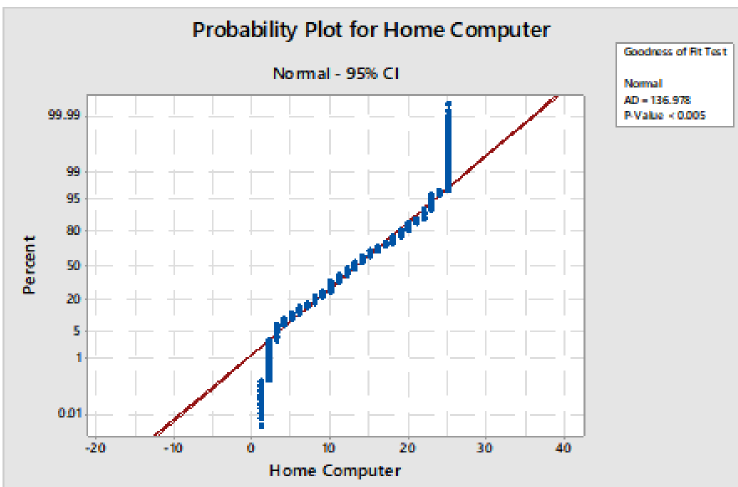
ML Estimates of Distribution Parameters

Distribution	Location	Shape	Scale	Threshold
Normal*	5.98686		4.14104	

** Scale: Adjusted ML estimate*

Home Computer





Descriptive Statistics

N	N*	Mean	StDev	Median	Minimum	Maximum	Skewness	Kurtosis
27259	0	13.4330	6.03836	13	1	25	0.0206132	-0.801386

Goodness of Fit Test

Distribution	AD	P
Normal	136.978	<0.005

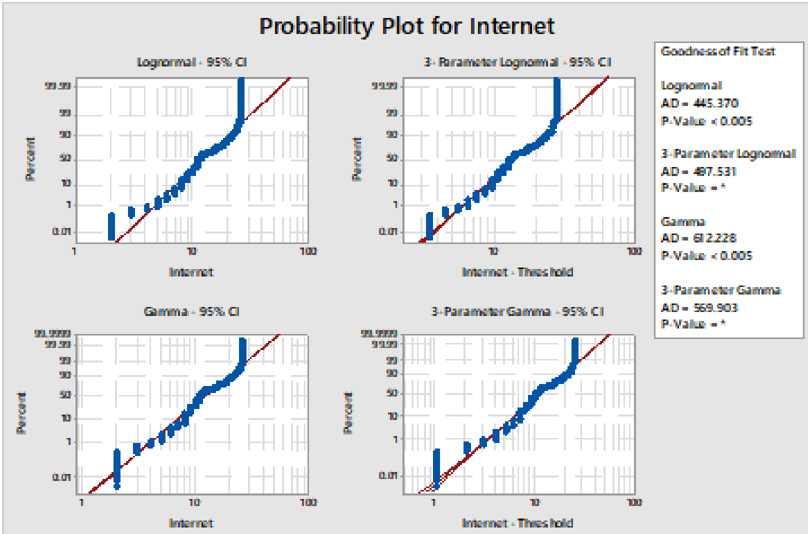
ML Estimates of Distribution Parameters

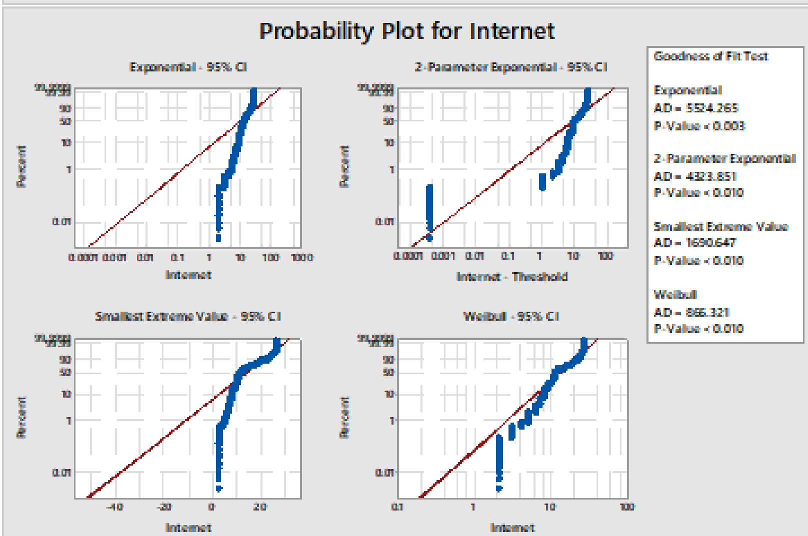
Distribution	Location	Shape	Scale	Threshold
Normal*	13.43296		6.03836	

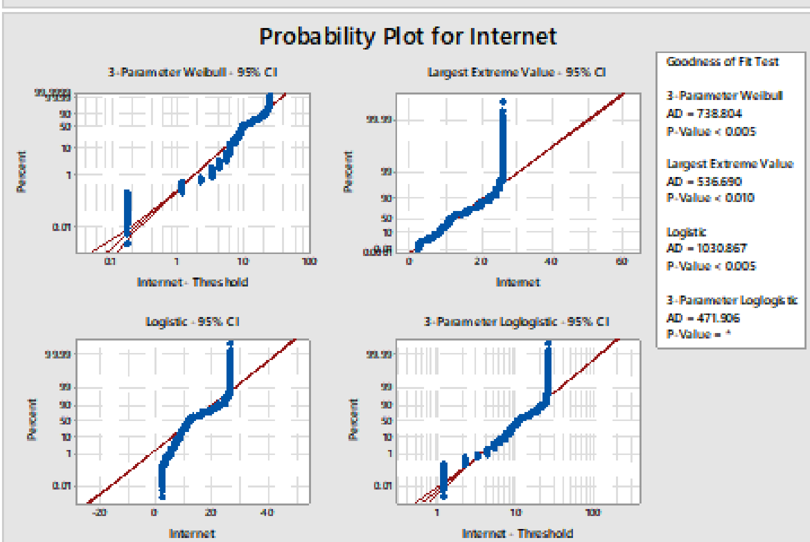
** Scale: Adjusted ML estimate*

Appendix 4: Tests for Other Distribution Types:

Internet







Descriptive Statistics

N	N*	Mean	StDev	Median	Minimum	Maximum	Skewness	Kurtosis
31602	0	13.6769	5.53288	12	2	26	0.696723	-0.578926

Goodness of Fit Test

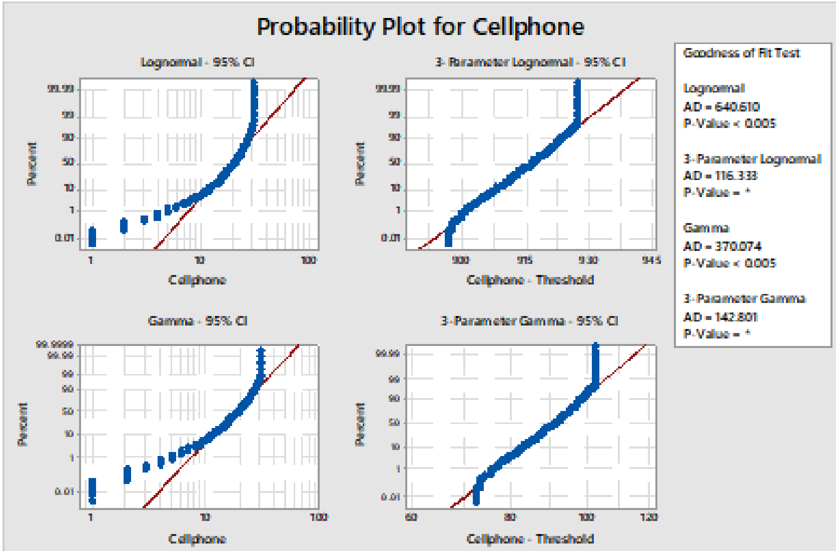
Distribution	AD	P	LRT P
Lognormal	445.370	<0.005	
3-Parameter Lognormal	497.531	*	0.000
Gamma	612.228	<0.005	
3-Parameter Gamma	569.903	*	0.000
Exponential	5524.265	<0.003	
2-Parameter Exponential	4323.851	<0.010	0.000
Smallest Extreme Value	1690.647	<0.010	
Weibull	866.321	<0.010	
3-Parameter Weibull	738.804	<0.005	0.000
Largest Extreme Value	536.690	<0.010	
Logistic	1030.867	<0.005	
3-Parameter Loglogistic	471.906	*	0.000

ML Estimates of Distribution Parameters

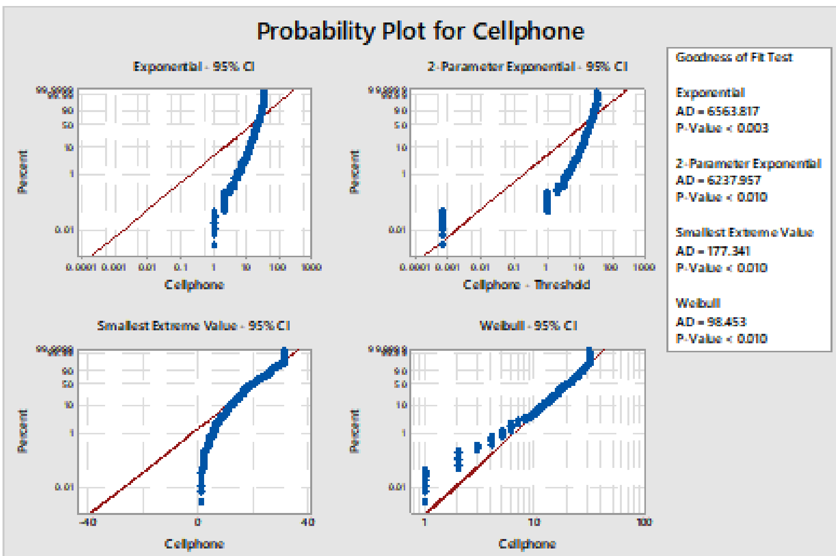
Distribution	Location	Shape	Scale	Threshold
Lognormal*	2.53493		0.40630	
3-Parameter Lognormal	2.64741		0.36215	-1.39418
Gamma		6.35138	2.15338	
3-Parameter Gamma		5.41035	2.35290	0.94694
Exponential			13.67692	
2-Parameter Exponential			11.67729	1.99963
Smallest Extreme Value	16.60981		5.89003	
Weibull		2.65239	15.43502	
3-Parameter Weibull		2.28602	13.41063	1.83170
Largest Extreme Value	11.13145		4.29203	
Logistic	13.06936		3.20342	
3-Parameter Loglogistic	2.44982		0.25357	0.86492

** Scale: Adjusted ML estimate*

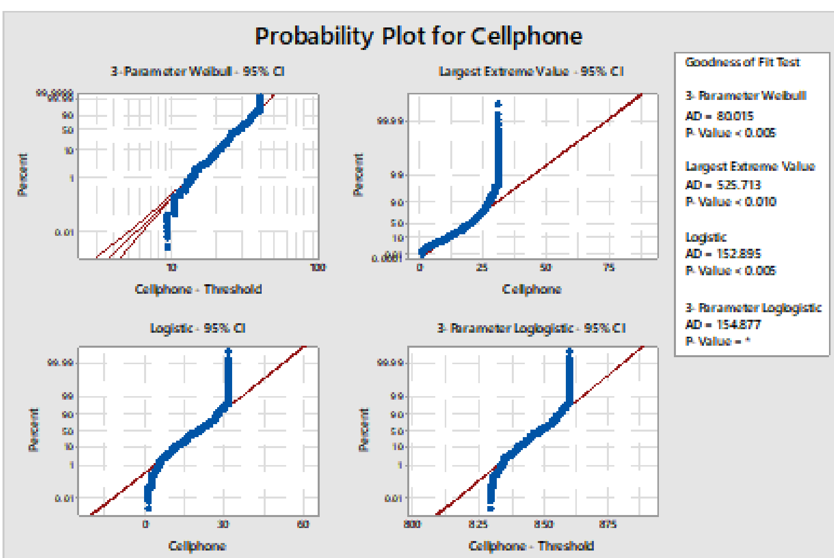
Cellphone



Probability Plot for Cellphone
Lognormal - 95% CI
3-Parameter Lognormal - 95% CI
Gamma - 95% CI
3-Parameter Gamma - 95% CI
Percent
Cellphone
Cellphone - Threshold
Goodness of Fit Test
Lognormal
AD = 640.610
P-Value < 0.005
3-Parameter Lognormal
AD = 116.333
P-Value = *
Gamma
AD = 370.074
P-Value < 0.005
3-Parameter Gamma
AD = 142.801
P-Value = *



Probability Plot for Cellphone
Exponential - 95% CI
2-Parameter Exponential - 95% CI
Smallest Extreme Value - 95% CI
Weibull - 95% CI
Percent
Cellphone
Cellphone - Threshold
Goodness of Fit Test
Exponential
AD = 6563.817
P-Value < 0.003
2-Parameter Exponential
AD = 6237.957
P-Value < 0.010
Smallest Extreme Value
AD = 177.341
P-Value < 0.010
Weibull
AD = 98.453
P-Value < 0.010



Probability Plot for Cellphone
3-Parameter Weibull - 95% CI
Largest Extreme Value - 95% CI
Logistic - 95% CI
3-Parameter Loglogistic - 95% CI
Percent
Cellphone
Cellphone - Threshold
Goodness of Fit Test
3-Parameter Weibull
AD = 80.015
P-Value < 0.005
Largest Extreme Value
AD = 525.713
P-Value < 0.010
Logistic
AD = 152.895
P-Value < 0.005
3-Parameter Loglogistic
AD = 154.877
P-Value = *

Distribution Identification for Cellphone

3-Parameter Lognormal

*** WARNING * Newton-Raphson algorithm has not converged after 100 iterations. * WARNING * Convergence has not been reached for the log-likelihood criterion. * WARNING * Convergence has not been reached for the parameter estimates criterion.**

3-Parameter Gamma

*** WARNING * Newton-Raphson algorithm has not converged after 100 iterations. * WARNING * Convergence has not been reached for the parameter estimates criterion.**

3-Parameter Loglogistic

*** WARNING * Newton-Raphson algorithm has not converged after 100 iterations.**
*** WARNING * Convergence has not been reached for the parameter estimates criterion.**

Descriptive Statistics

N	N*	Mean	StDev	Median	Minimum	Maximum	Skewness	Kurtosis
29731	0	19.9878	5.99459	20	1	31	-0.295103	-0.397139

Goodness of Fit Test

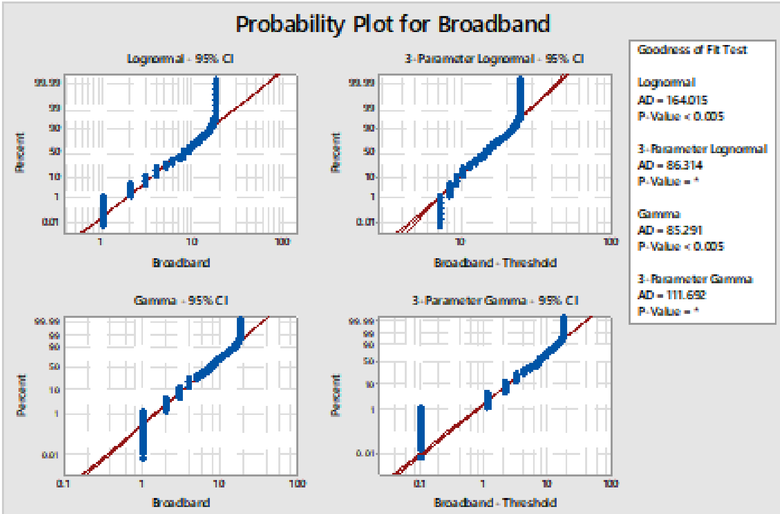
Distribution	AD	P	LRT P
Lognormal	640.610	<0.005	
3-Parameter Lognormal	116.333	*	0.000
Gamma	370.074	<0.005	
3-Parameter Gamma	142.801	*	0.000
Exponential	6563.817	<0.003	
2-Parameter Exponential	6237.957	<0.010	0.000
Smallest Extreme Value	177.341	<0.010	
Weibull	98.453	<0.010	
3-Parameter Weibull	80.015	<0.005	0.000
Largest Extreme Value	525.713	<0.010	
Logistic	152.895	<0.005	
3-Parameter Loglogistic	154.877	*	0.000

ML Estimates of Distribution Parameters

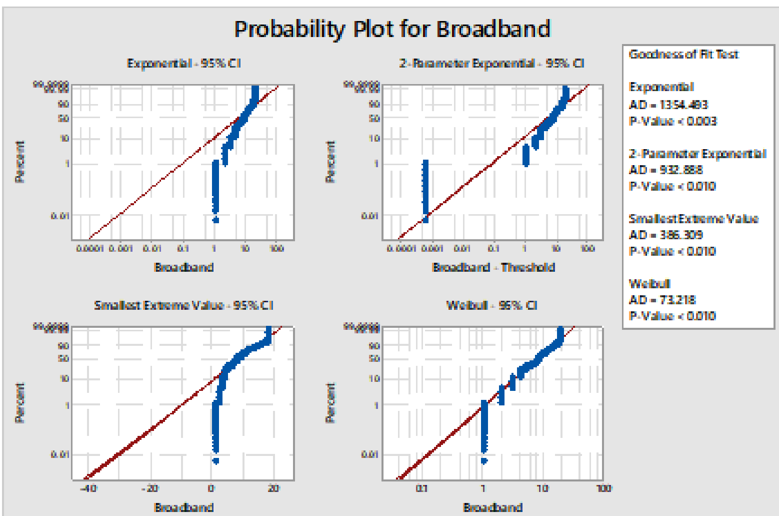
Distribution	Location	Shape	Scale	Threshold
Lognormal*	2.93745		0.37131	
3-Parameter Lognormal	6.81982		0.00655	-895.84631
Gamma		8.83408	2.26257	
3-Parameter Gamma		224.55343	0.40609	-71.23997
Exponential			19.98776	
2-Parameter Exponential			18.98840	0.99936
Smallest Extreme Value	22.90002		5.32226	
Weibull		3.81549	22.11684	
3-Parameter Weibull		5.47111	30.51025	-8.14253
Largest Extreme Value	16.91720		6.18965	
Logistic	20.16150		3.49697	
3-Parameter Loglogistic	6.74366		0.00412	-828.49898

** Scale: Adjusted ML estimate*

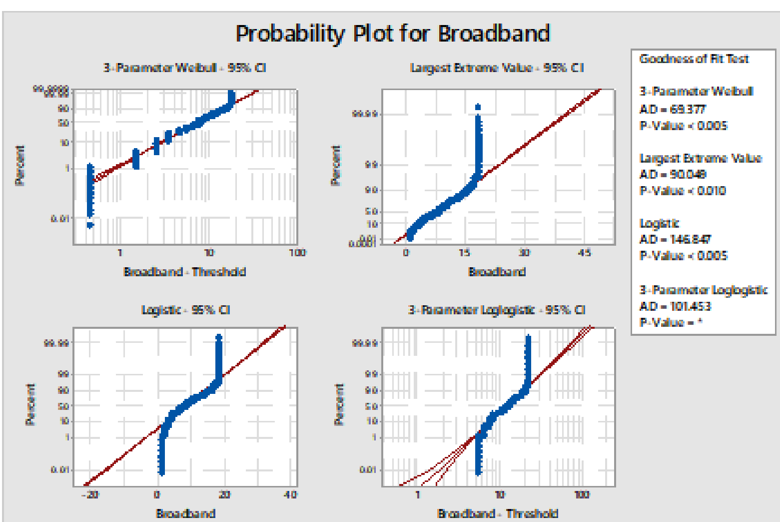
Broadband



Probability Plot for Broadband
Lognormal - 95% CI
3-Parameter Lognormal - 95% CI
Gamma - 95% CI
3-Parameter Gamma - 95% CI
Percent
Broadband
Broadband - Threshold
Goodness of Fit Test
Lognormal
AD = 164.015
P-Value < 0.005
3-Parameter Lognormal
AD = 86.314
P-Value = *
Gamma
AD = 85.291
P-Value < 0.005
3-Parameter Gamma
AD = 111.692
P-Value = *



Probability Plot for Broadband
Exponential - 95% CI
2-Parameter Exponential - 95% CI
Smallest Extreme Value - 95% CI
Weibull - 95% CI
Percent
Broadband
Broadband - Threshold
Goodness of Fit Test
Exponential
AD = 1354.493
P-Value < 0.003
2-Parameter Exponential
AD = 932.888
P-Value < 0.010
Smallest Extreme Value
AD = 386.309
P-Value < 0.010
Weibull
AD = 73.218
P-Value < 0.010



Probability Plot for Broadband
3-Parameter Weibull - 95% CI
Largest Extreme Value - 95% CI
Logistic - 95% CI
3-Parameter Loglogistic - 95% CI
Percent
Broadband
Broadband - Threshold
Goodness of Fit Test
3-Parameter Weibull
AD = 69.377
P-Value < 0.005
Largest Extreme Value
AD = 90.049
P-Value < 0.010
Logistic
AD = 146.847
P-Value < 0.005
3-Parameter Loglogistic
AD = 101.453
P-Value = *

Distribution Identification for Broadband

3-Parameter Gamma

*** WARNING * Variance/Covariance matrix of estimated parameters does not exist. The threshold parameter is assumed fixed when calculating confidence intervals.**

2-Parameter Exponential

*** WARNING * Variance/Covariance matrix of estimated parameters does not exist. The threshold parameter is assumed fixed when calculating confidence intervals.**

Descriptive Statistics

N	N*	Mean	StDev	Median	Minimum	Maximum	Skewness	Kurtosis
13017	0	8.71084	4.39484	8	1	18	0.433508	-0.681781

Goodness of Fit Test

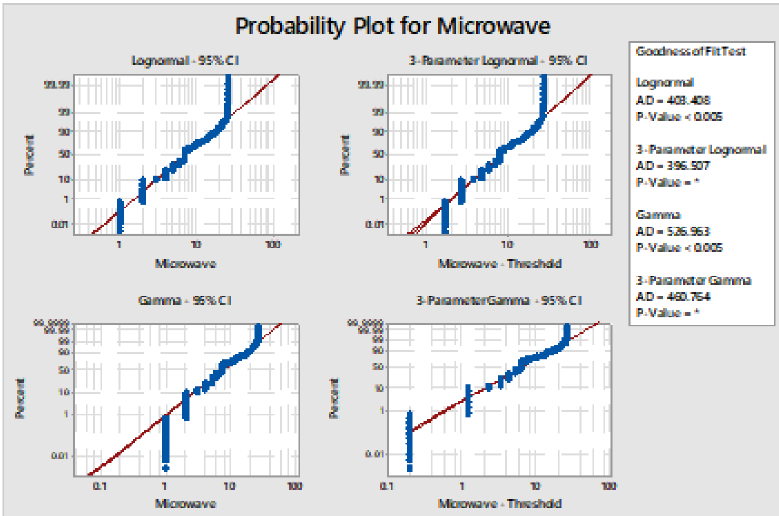
Distribution	AD	P	LRT P
Lognormal	164.015	<0.005	
3-Parameter Lognormal	86.314	*	0.000
Gamma	85.291	<0.005	
3-Parameter Gamma	111.692	*	1.000
Exponential	1354.493	<0.003	
2-Parameter Exponential	932.888	<0.010	0.000
Smallest Extreme Value	386.309	<0.010	
Weibull	73.218	<0.010	
3-Parameter Weibull	69.377	<0.005	0.000
Largest Extreme Value	90.049	<0.010	
Logistic	146.847	<0.005	
3-Parameter Loglogistic	101.453	*	0.000

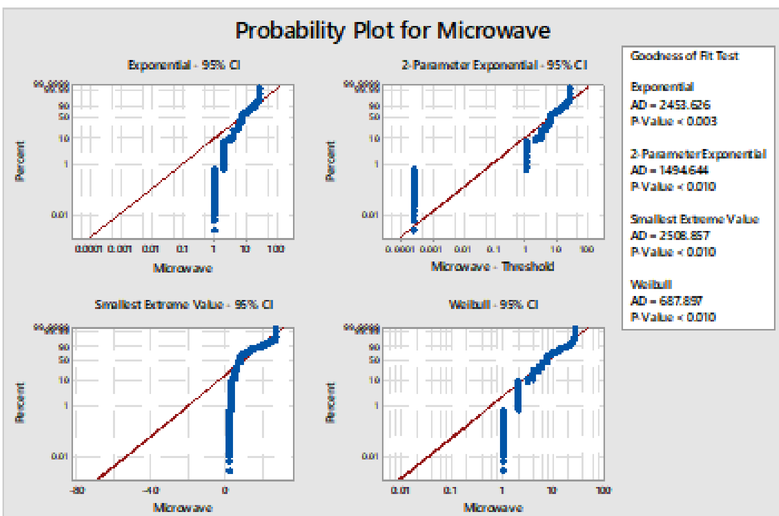
ML Estimates of Distribution Parameters

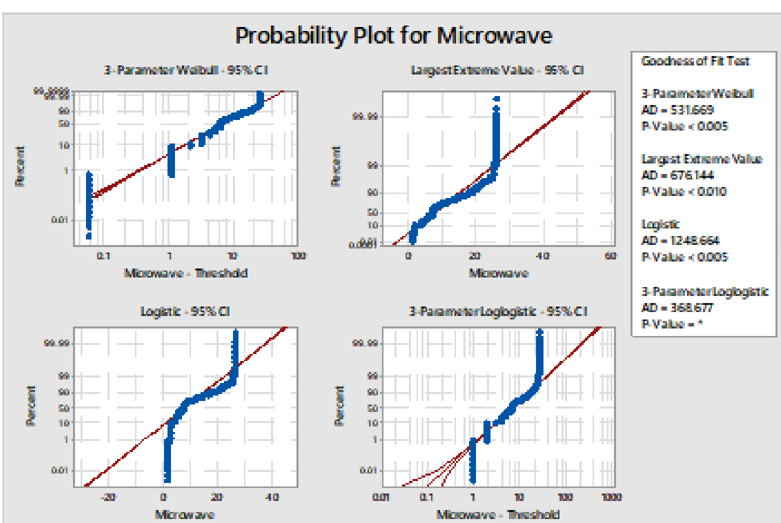
Distribution	Location	Shape	Scale	Threshold
Lognormal*	2.01294		0.59152	
3-Parameter Lognormal	2.66050		0.29730	-6.22993
Gamma		3.45536	2.52096	
3-Parameter Gamma		2.41477	3.23550	0.89782
Exponential			8.71084	
2-Parameter Exponential			7.71143	0.99941
Smallest Extreme Value	10.99115		4.49527	
Weibull		2.10257	9.85398	
3-Parameter Weibull		1.92754	9.18090	0.56709
Largest Extreme Value	6.61579		3.67596	
Logistic	8.44971		2.57176	
3-Parameter Loglogistic	2.51421		0.20458	-4.29969

** Scale: Adjusted ML estimate*

Microwave


Probability Plot for Microwave
Lognormal - 95% CI
3-Parameter Lognormal - 95% CI
Gamma - 95% CI
3-Parameter Gamma - 95% CI
Percent
Microwave
Microwave - Threshold
Goodness of Fit Test
Lognormal
AD = 408.408
P-Value < 0.005
3-Parameter Lognormal
AD = 396.507
P-Value = *
Gamma
AD = 526.963
P-Value < 0.005
3-Parameter Gamma
AD = 460.764
P-Value = *


Probability Plot for Microwave
Exponential - 95% CI
2-Parameter Exponential - 95% CI
Smallest Extreme Value - 95% CI
Weibull - 95% CI
Percent
Microwave
Microwave - Threshold
Goodness of Fit Test
Exponential
AD = 2453.626
P-Value < 0.003
2-Parameter Exponential
AD = 1494.644
P-Value < 0.010
Smallest Extreme Value
AD = 2508.857
P-Value < 0.010
Weibull
AD = 687.897
P-Value < 0.010


Probability Plot for Microwave
3-Parameter Weibull - 95% CI
Largest Extreme Value - 95% CI
Logistic - 95% CI
3-Parameter Loglogistic - 95% CI
Percent
Microwave
Microwave - Threshold
Goodness of Fit Test
3-Parameter Weibull
AD = 531.669
P-Value < 0.005
Largest Extreme Value
AD = 676.144
P-Value < 0.010
Logistic
AD = 1248.664
P-Value < 0.005
3-Parameter Loglogistic
AD = 368.677
P-Value = *

Distribution Identification for Microwave

Descriptive Statistics

N	N*	Mean	StDev	Median	Minimum	Maximum	Skewness	Kurtosis
32035	0	9.04892	5.88787	7	1	26	1.18452	0.629356

Goodness of Fit Test

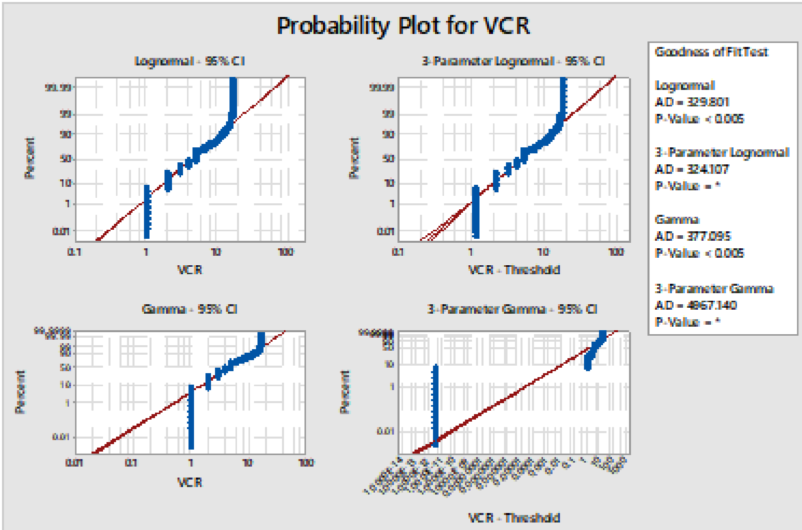
Distribution	AD	P	LRT P
Lognormal	403.408	<0.005	
3-Parameter Lognormal	396.507	*	0.000
Gamma	526.963	<0.005	
3-Parameter Gamma	460.764	*	0.000
Exponential	2453.626	<0.003	
2-Parameter Exponential	1494.644	<0.010	0.000
Smallest Extreme Value	2508.857	<0.010	
Weibull	687.897	<0.010	
3-Parameter Weibull	531.669	<0.005	0.000
Largest Extreme Value	676.144	<0.010	
Logistic	1248.664	<0.005	
3-Parameter Loglogistic	368.677	*	0.095

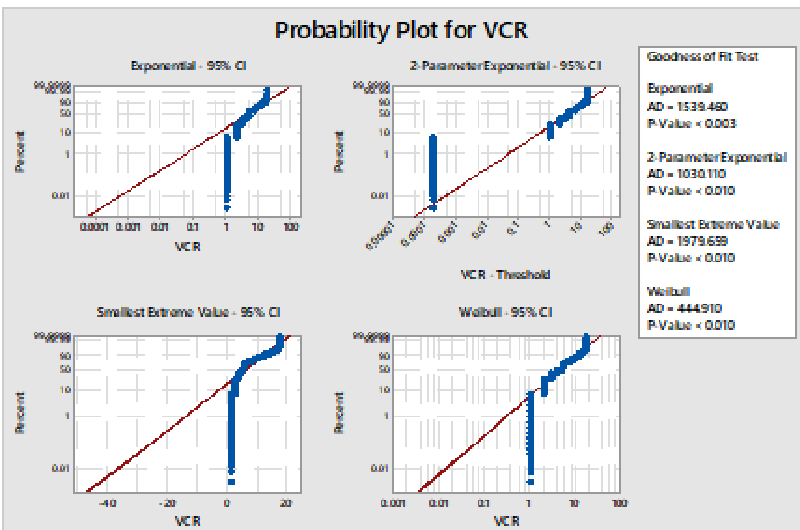
ML Estimates of Distribution Parameters

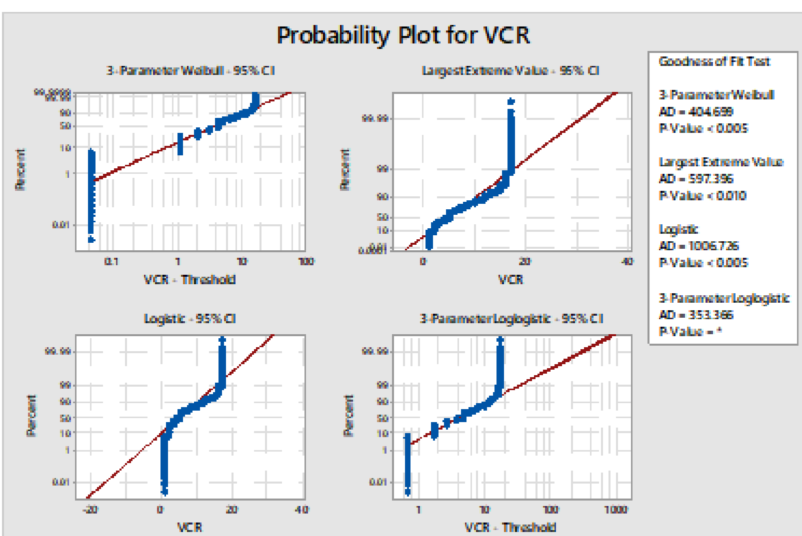
Distribution	Location	Shape	Scale	Threshold
Lognormal*	1.99825		0.65686	
3-Parameter Lognormal	2.09857		0.59232	-0.63813
Gamma		2.60087	3.47918	
3-Parameter Gamma		2.00574	4.11020	0.80491
Exponential			9.04892	
2-Parameter Exponential			8.04917	0.99975
Smallest Extreme Value	12.28604		7.00517	
Weibull		1.64938	10.18604	
3-Parameter Weibull		1.43343	8.94968	0.94279
Largest Extreme Value	6.49389		4.05561	
Logistic	8.16281		3.16700	
3-Parameter Loglogistic	1.99151		0.37611	0.08199

** Scale: Adjusted ML estimate*

VCR


Probability Plot for VCR
Lognormal - 95% CI
3-Parameter Lognormal - 95% CI
Gamma - 95% CI
3-Parameter Gamma - 95% CI
Percent
VCR
VCR - Threshold
Goodness of Fit Test
Lognormal
AD = 329.801
P-Value < 0.005
3-Parameter Lognormal
AD = 324.107
P-Value = *
Gamma
AD = 377.095
P-Value < 0.005
3-Parameter Gamma
AD = 4967.140
P-Value = *


Probability Plot for VCR
Exponential - 95% CI
2-Parameter Exponential - 95% CI
Smallest Extreme Value - 95% CI
Weibull - 95% CI
Percent
VCR
VCR - Threshold
Goodness of Fit Test
Exponential
AD = 1539.460
P-Value < 0.003
2-Parameter Exponential
AD = 1030.110
P-Value < 0.010
Smallest Extreme Value
AD = 1979.659
P-Value < 0.010
Weibull
AD = 444.910
P-Value < 0.010


Probability Plot for VCR
3-Parameter Weibull - 95% CI
Largest Extreme Value - 95% CI
Logistic - 95% CI
3-Parameter Loglogistic - 95% CI
Percent
VCR
VCR - Threshold
Goodness of Fit Test
3-Parameter Weibull
AD = 404.699
P-Value < 0.005
Largest Extreme Value
AD = 597.396
P-Value < 0.010
Logistic
AD = 1006.726
P-Value < 0.005
3-Parameter Loglogistic
AD = 353.366
P-Value = *

Distribution Identification for VCR

3-Parameter Gamma

*** WARNING * Variance/Covariance matrix of estimated parameters does not exist. The threshold parameter is assumed fixed when calculating confidence intervals.**

Descriptive Statistics

N	N*	Mean	StDev	Median	Minimum	Maximum	Skewness	Kurtosis
29143	0	5.98686	4.14104	5	1	17	1.03634	0.156678

Goodness of Fit Test

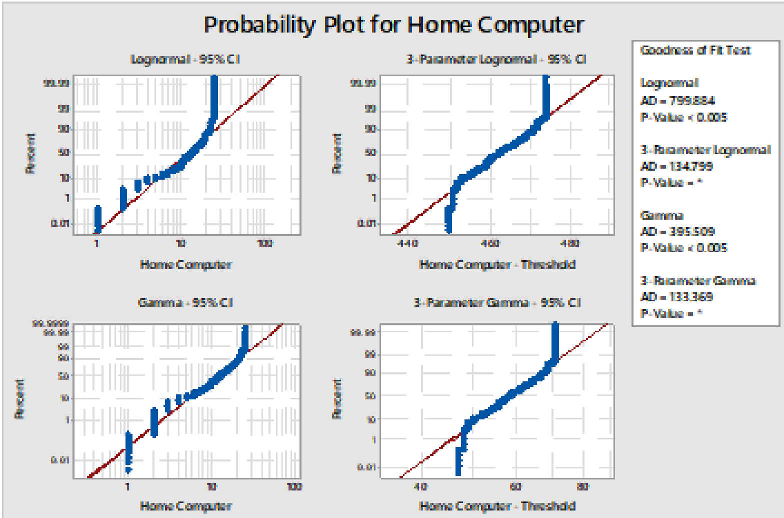
Distribution	AD	P	LRT P
Lognormal	329.801	<0.005	
3-Parameter Lognormal	324.107	*	0.000
Gamma	377.095	<0.005	
3-Parameter Gamma	4967.140	*	0.000
Exponential	1539.460	<0.003	
2-Parameter Exponential	1030.110	<0.010	0.000
Smallest Extreme Value	1979.659	<0.010	
Weibull	444.910	<0.010	
3-Parameter Weibull	404.699	<0.005	0.000
Largest Extreme Value	597.396	<0.010	
Logistic	1006.726	<0.005	
3-Parameter Loglogistic	353.366	*	0.000

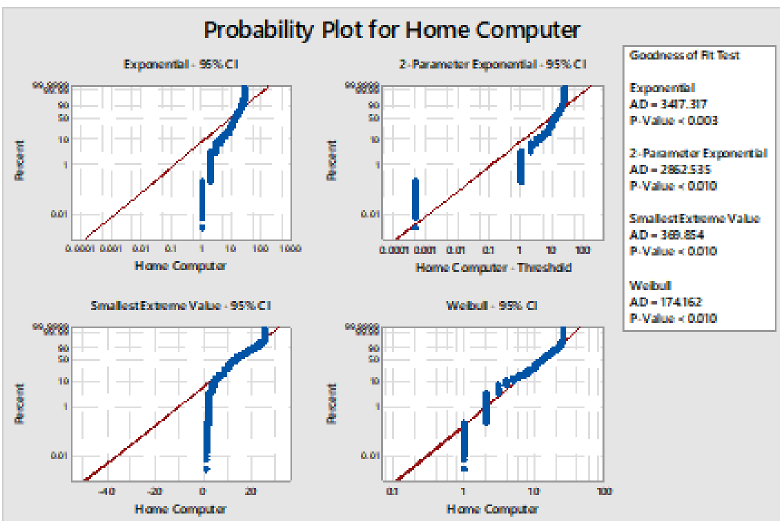
ML Estimates of Distribution Parameters

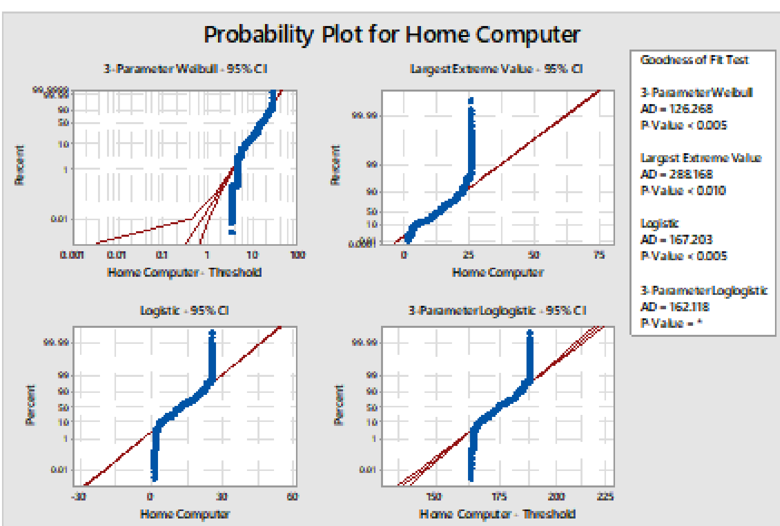
Distribution	Location	Shape	Scale	Threshold
Lognormal*	1.54472		0.72566	
3-Parameter Lognormal	1.58159		0.69913	-0.13608
Gamma		2.19423	2.72845	
3-Parameter Gamma		0.35645	13.99037	1.00000
Exponential			5.98686	
2-Parameter Exponential			4.98703	0.99983
Smallest Extreme Value	8.23921		4.76368	
Weibull		1.53260	6.68826	
3-Parameter Weibull		1.12258	5.22976	0.95592
Largest Extreme Value	4.15760		2.91020	
Logistic	5.41590		2.29175	
3-Parameter Loglogistic	1.47911		0.46262	0.31307

** Scale: Adjusted ML estimate*

Home Computer







Distribution Identification for Home Computer

3-Parameter Lognormal

*** WARNING * Newton-Raphson algorithm has not converged after 100 iterations.**
*** WARNING * Convergence has not been reached for the log-likelihood criterion.**
*** WARNING * Convergence has not been reached for the parameter estimates criterion.**

3-Parameter Gamma

*** WARNING * Newton-Raphson algorithm has not converged after 100 iterations.**
*** WARNING * Convergence has not been reached for the log-likelihood criterion.**
*** WARNING * Convergence has not been reached for the parameter estimates criterion.**

Descriptive Statistics

N	N*	Mean	StDev	Median	Minimum	Maximum	Skewness	Kurtosis
27259	0	13.4330	6.03836	13	1	25	0.0206132	-0.801386

Goodness of Fit Test

Distribution	AD	P	LRT P
Lognormal	799.884	<0.005	
3-Parameter Lognormal	134.799	*	0.000
Gamma	395.509	<0.005	
3-Parameter Gamma	133.369	*	0.000
Exponential	3417.317	<0.003	
2-Parameter Exponential	2862.535	<0.010	0.000
Smallest Extreme Value	369.854	<0.010	
Weibull	174.162	<0.010	
3-Parameter Weibull	126.268	<0.005	0.000
Largest Extreme Value	288.168	<0.010	
Logistic	167.203	<0.005	
3-Parameter Loglogistic	126.268	<0.005	0.000

ML Estimates of Distribution Parameters

Distribution	Location	Shape	Scale	Threshold
Lognormal*	2.45716		0.59537	
3-Parameter Lognormal	6.13531		0.01307	-448.48973
Gamma		3.71589	3.61500	
3-Parameter Gamma		94.83852	0.62337	-45.72691
Exponential			13.43296	
2-Parameter Exponential			12.43341	0.99954
Smallest Extreme Value	16.45261		5.65786	
Weibull		2.37108	15.12902	
3-Parameter Weibull		2.89974	17.79100	-2.40842
Largest Extreme Value	10.42696		5.63438	
Logistic	13.38740		3.56798	
3-Parameter Loglogistic	5.16854		0.02030	-162.32515

** Scale: Adjusted ML estimate*

3.3 The Ontological Emergence of Creativity

Abstract

At its core, creativity is the act of assembling two or more knowledge elements (thoughts, ideas, perceptions, or conceptions) into new knowledge elements. Applying that new knowledge element in an appropriate way requires some skill. The conflation of skill and creativity has resulted in challenges in defining creativity and in developing a holistic theory of creativity. While there have been many attempts to come up with a broadly accepted definition of creativity, despite those who claim there is a standard definition, there is still a great deal of disagreement in the literature on this topic. Notwithstanding the ongoing debate, there are similarities among most of the proposed definitions, to the point where contributors to the discussion seem to be limited by functional fixedness. In this conceptual paper, the philosophical concepts of fundamental ontology and ontological dependence are used to present a philosophical argument for a new way of thinking about creativity, and its definition, based on complexity theory and emergence. This changes the questions surrounding creativity from ones such as 'how can we enhance creativity?' to 'what parameters of a complex adaptive system can be adjusted to increase the probability of creative outcomes?'

Keywords: creativity, definition of creativity, complexity science, complexity theory, complex adaptive systems, emergence, ontological emergence.

3.3.1 Introduction

While some creativity researchers would have us believe that the issue of a definition of creativity has been put to rest (Carson, 2010; Runco & Jaeger, 2012), others have a different view (Colin, 2017; Hennessey & Amabile, 2010). It has been an ongoing debate, at least since Guilford (1950) launched the modern era of creativity research almost 70 years ago. During the period from the 1950s to the present, theories of creativity have followed a general trend, evolving from psychometric and histometric, to psychological, social psychological, and social, to componential and other systems-based theories (K. R. Sawyer, 2012). The next logical step in this evolutionary trend in creativity theories is a complexity theory of creativity. This paper discusses one type of complexity theory – complex adaptive systems – in section 2. Just as the physical and social sciences have moved (or are moving) from systems theory to complex systems theories (see, for example, physics: Hawking, 2000; physics and biological evolution: S. Kauffman, 2010; sciences in general: Page, 2009; social science and others: K. R. Sawyer, 2005), so too is it now time for the emergence of a complexity theory of creativity.

While this paper does not tackle the task of articulating a complete complexity theory of creativity, it does attempt to develop a definition of creativity based on one characteristic of complex adaptive systems: emergence. Emergence is discussed in section 3. However, emergence is not without its own controversies, having been understood in different ways. This paper relies on ontological emergence, defined as fundamental and dependent, to develop a definition of creativity. These concepts are discussed in section 6. To fully appreciate this discussion, some background in the philosophical concepts of physicalism and dualism are first presented in sections 4 and 5 respectively.

Section 7 gives an overview of some of the various opinions and discussions that have been going on for at least the past 70 years about the definition of creativity. In section 8, ontological emergence and creativity are brought together to develop a complexity-theory-based definition of creativity, while hinting at an initial complexity-theory-based theory of creativity. That is, a theory of creativity with an ontological emergence definition of creativity at its core. Finally, section 9 considers some of the possible implications of this work and suggests future research that would help support and extend a complexity theory of creativity.

3.3.2 Complex Adaptive Systems

Clearly articulating the concept of *complexity* – as it is used in the terms *complexity science* and *complexity theory* – is challenging. This is so at least in part because it means different things to different people. John Holland's (2012) differentiation between *complex physical systems* and *complex adaptive systems* can help us narrow down exactly what is meant by complexity in this paper. Holland defines complex physical systems as "arrays of elements, in which interactions typically depend only on effects propagated from nearest neighbours" (p. 6). As an example, imagine a pile of sand, where each grain of sand rests against several of its nearest neighbours. An individual grain of sand is only disturbed if one of its nearest neighbours is disturbed, or if it is directly acted upon by something from the environment outside of the sandpile. Holland describes complex adaptive systems as consisting of elements (in complexity studies these elements are typically referred to as agents) that adapt as they interact with other agents and their environment. Agents in complex adaptive systems can interact with other agents that are not close by and they can change how they interact based on the information they glean from other agents and their environment. This paper will only be concerned with complex adaptive systems.

Scott Page (2009) describes complex adaptive systems as ones in which agents are interconnected, interdependent, diverse, and adaptive. Page also notes that "A system will be said to be complex if the whole transcends the parts" (p. 3). With this statement, Page is implying that complex adaptive systems always display emergence and that emergence is one of the properties that define a complex system. While there are many variations in the descriptions and definitions of complex adaptive systems (in addition to Page and Holland, see also: Bar-Yam, 1997; N. Johnson, 2009; Kauffman, 1995; Mitchell, 2009), there are also many similarities.[52]

This paper draws heavily from Page's definition of complex adaptive systems, but further integrates the concept of emergence, resulting in a unique definition for both terms: a complex adaptive system is any set of diverse, interdependent agents that interact with and adapt to each other and their environment, thereby resulting in a new, emergent entity, entities, or agents that could not have been predicted from complete knowledge of the agents and their relationships. In this sense, complexity and emergence are intertwined.

To fully appreciate this definition of a complex adaptive system, several other definitions are required. An entity is defined here as something that has its own existence, separate from, but not necessarily independent of, the elements which make it up, or from which it arose. An entity may be concrete or abstract, material or immaterial. Specifically, an

---

[52] For a discussion of some of the similarities and differences, see Lambert, P. A. (2018). The Order - Chaos Dynamic of Creativity. *Manuscript Submitted for Publication.* https://www.researchgate.net/publication/328890717_The_Order-Chaos_Dynamic_of_Creativity

entity does not have to exist physically. An agent is an entity that interacts with other agents and its environment and adapts its behaviour based on those interactions. Emergence is further discussed and defined in the next section.

Complete knowledge, in this case, refers to what has become known as Laplace's Demon. In 1814, Pierre-Simon Laplace published a thought experiment in which he argued that if a super-intelligence were to know the positions, velocities of, and forces acting upon, every particle in the universe, this super-intelligence would know everything about the universe, past and present.

> Given for one instant an intelligence which could comprehend all the forces by which nature is animated and the respective situation of the beings who compose it-an intelligence sufficiently vast to submit these data to analysis-it would embrace in the same formula the movements of the greatest bodies of the universe and those of the lightest atom; for it, nothing would be uncertain and the future, as the past, would be present to its eyes. (Laplace, 1902, p. 4)

3.3.3 Emergence

Bar-Yam (1997) also defines complexity and emergence in terms of each other, stating that "A complex system is a system formed out of many components whose behaviour is emergent, that is, the behaviour of the system cannot be simply inferred from the behaviour of its components" (p. 10). He elaborates by noting that emergent behaviours cannot be understood by studying the parts. That is, reductionism is insufficient to understand emergent properties. Camazine et al. (2003), define emergence as "A process by which a system of interacting subunits acquires qualitatively new properties that cannot be understood as the simple addition of their individual contributions" (p. 31). Philip Anderson

(2008), defines “emergence as the appearance as the scale is increased of properties unrelated to those of the substrate” (p. 6).

This paper is based on a definition of emergence that is derived from the definition of complex adaptive systems presented in the previous section. Emergence is the arising of a new entity, entities, or agents, as a result of the interaction of a set of diverse, interdependent agents that adapt to each other and their environment. The new entity, entities, or agents could not have been predicted from a complete knowledge of the agents and their relationships.

Examples of emergence include consciousness, which is thought to emerge from the interaction of billions of synapses (Nunez, 2016), the intelligent behaviour of ant colonies emerging from many individual ants following simple rules (S. Johnson, 2002), economies and the stock market (N. Johnson, 2009), as well as human societies and cities (K. R. Sawyer, 2005), emerging from the interaction of individual people, and life emerging from the interaction of individual cells (S. A. Kauffman, 1995).[53]

---

[53] As an aside: Emergence also occurs in complex physical systems. For example, the wetness, or liquidity, of water is not a property of individual hydrogen or oxygen atoms, their sub-atomic constituents, or even of individual water molecules. Liquidity is an emergent property of a sufficient number of water molecules within a certain temperature range (Raggett, 2012) (In fact, research has shown that six or more water molecules are required to result in “wateriness” (Coghlan, 1997).) Some people suggest that wetness is not emergent, as defined above, because it can be predicted through quantum mechanics (see, for example, Buxbaum, 2013), while others might suggest that the indeterminacy of quantum mechanics means we can’t predict anything about the properties of H_2O from knowledge of its constituent parts (Corning, 2002, Halvorson, 2015). Fortunately, this and other controversies surrounding emergence are not a concern for the argument developed and presented in this paper, since the argument is based on emergence in complex adaptive systems, not complex physical systems.

Although emergence occurs as a result of interactions among agents, the emergent entity – the higher-level system – also affects the agents. This is referred to as downward causation (K. R. Sawyer, 2005). For example, individual people are influenced and affected by society, investors are influenced by the stock market, and our minds have some control over our brains. At the same time, the actions of the individual agent in each case – an individual member of society, investor, or synapse – have some impact on the whole – the higher-level entity. Together, these cross-level effects are known as the macro-micro link (J. Huber, 1991).

Emergence can also occur over multiple levels. For instance, macromolecules such as proteins emerge from the interaction of molecules; macromolecules form cells, cells form tissue, tissues form organs and organ systems, organs form organisms, organisms form populations, populations form communities, social systems and ecosystems, and ecosystems form biospheres (Lobo, 2008). This is important because "A very small change in a single macromolecule can have a profound effect on an organism, or even a population, when magnified through levels of complexity" (Lobo, 2008, para. 7).

In order to understand the link between creativity and emergence that this paper proposes, it is helpful to understand the philosophical concepts of physicalism and dualism, since emergence is what some have suggested is a middle path between the two (Niño El-Hani & Pihlström, 2002), while others have suggested it is a "position which weaves together both dualism and physicalism" (Stoljar, 2015, section 9) .

3.3.4 Physicalism

The terms *physicalism* and *materialism* have different histories but are now often used interchangeably (Stoljar, 2015). However, the details of their different histories are not

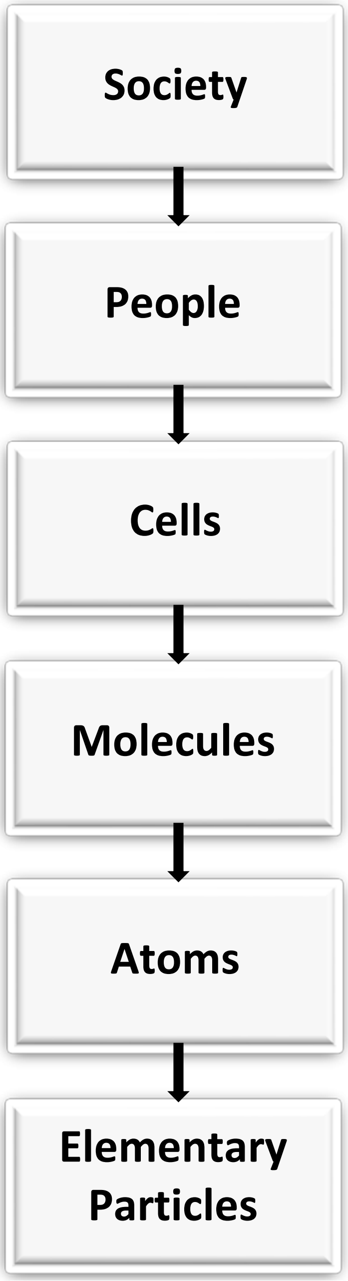


Figure 22: Supervenience

important to the discussion in this paper. Physicalism is the theory that everything is physical or that everything *supervenes* on the physical. Alternatively, materialism is the theory that everything supervenes on the material.

Supervenience states that upper-level properties are more than just the result of lower-level properties, they are inextricably linked – they supervene on the lower level. For example, the properties of a society supervene on the people that are part of that society, while the properties of these living people supervene on the cells that make them up. Cells supervene on molecules and molecules on elementary particles (see Figure 22). Any change in upper-level properties is the result of and, ultimately, can be explained by a change in elementary particles.

David Lewis (1986), explains supervenience nicely with the analogy of a dot-matrix picture. A dot-matrix picture has a global property, which is the picture itself, that is, the pattern in the dots. This global property – the pattern, the picture – supervenes on the dots and the spaces between dots. Supervenience means that no two pictures could have different global properties without there being some difference in the dots. This also means that an exact replica of the dots and spaces will produce the same global properties. Of course, this example is based on a simple system. If the dots were all agents that changed (adapted) based on changes in the other dots and changes in their environment (the space between dots), then the dots would constitute a complex adaptive system and one could argue that it is impossible to make an exact replica of such as system because of the requirement for infinite precision. The complex adaptive system property of sensitive dependence on initial conditions suggests that even the slightest difference would become magnified over time, eventually resulting in a picture that looks nothing like the original.

Supervenience is one way of expressing a reductionist point of view, in the same way as Stephen Weinberg's dictum that "The arrows of explanation point down to a common source" (Weinberg, 1987, p. 436). That is, Weinberg believes that "society is to be explained in terms of people, people in terms of organs, organs by cells, cells by biochemistry, biochemistry by chemistry, and chemistry by physics" (S. Kauffman, 2010, p, 10). In other words, applying physicalism to social groups leads to the conclusion that they are the result of elementary particles – that social properties supervene on psychological properties, which supervene on biological properties, etc., with everything ultimately supervening on the most elementary particles – whatever they may be.[54] Mind-body supervenience means that all mental states, including consciousness, can be explained by the physical parts of our bodies, be it the interaction of 100 billion neurons, or those plus the interactions of other physical elements. From this perspective, the mind is a by-product of the physical system. However, at least since the time of Aristotle, there have been debates about whether it is possible to reduce higher level states, such as mental states (including consciousness), to the physical properties of lower level physical elements, be they neurons, cells, or elementary particles.

---

[54] Currently thought to be four different types of fermion particles, their four anti-mater particle counterparts, and two types of boson particles.

Physicalism is related to the reductionist philosophy, which is a mechanistic view that life and other higher-level systems can be explained and understood by way of a thorough understanding of their constituent parts. Physicalism is also a monistic view of the world. Contrasting with this monistic view is dualism.

3.3.5 Dualism

Dualism can be contrasted with *monism* and *pluralism*. Monism is the theory that there is only one category of thing, or entity, while pluralism is the theory that there are many (H. Robinson, 2016). Physicalism is one type of monism. The other types will not be discussed here since they are not germane to the discussion and, in fact, could be counterproductive. Dualism is the theory that reality consists of more than just the physical; that non-physical entities exist. This theory is most often applied to the mind, but it can also apply to life, societies and other global properties that appear to arise out of the physical. When applied to the mind-body problem, dualism argues that the mind cannot be treated as merely a part of the physical world (H. Robinson, 2016). The dualist view is that both the physical and the non-physical – such as the mental – are real and neither is fully explained by the other.

An early form of dualism was vitalism, an anti-reductionist philosophy that posited a non-physical force or principal – a vital force – that made living entities distinct from non-living entities (Weber, 2011). Vitalism had largely fallen out of favour by the twentieth century (Bechtel & Richardson, 1998), while emergentism was arising to take its place. Emergentism is a dualist view that takes a middle ground, rejecting the idea of vital substances but retaining the idea of irreducible qualities (O'Connor & Wong, 2015). That is, emergent entities cannot be reduced to, nor explained by, the lower-level entities that give rise to them.

3.3.6 Ontology and Ontological Emergence

Ontology is the study of being and the study of related concepts such as becoming, reality, and existence. It deals with such basic questions as What things exist? What is real? Is there an objective reality?

Ontological Emergence: Elizabeth Barnes (2012), argues that making a claim that some entities are emergent is making a claim about the world's structure. That is, emergence relates to questions regarding the nature of reality, existence, or being, therefore, the existence and nature of emergence are ontological questions. By taking this perspective, emergentists are saying that "not everything about the world's structure can be explained in terms of smaller parts building into larger, more complex wholes" (p. 874). Barnes presents a theory of emergence that places limits on what should be considered emergent and how emergent entities can be understood in relation to other entities. She does this by appealing to *fundamentalist ontology* and *ontological dependence*.

The fundamentalist sees the world as existing in hierarchical levels. The lowest level – the level at which entities cannot be further broken down into constituent parts – is *fundamental* (Kim, 2008; Schaffer, 2003). Barnes (2012), argues that fundamentality does not come in degrees. An entity is either fundamental or it is not, while everything that is not fundamental is *derived* from fundamental entities. She further points out that the fundamentalist view does not have to be a physicalist view; entities can be physical or non-physical.

Barnes' theory of ontological emergence also draws on the concept of ontological dependence. She defines ontological dependence as occurring "in any situation in which there is something exactly like [the entity in question], you've got to have other things existing alongside it. You cannot ever have [the entity] by itself" (p. 880).

Combining fundamentality, dependence, and their counterparts yields a two by two matrix as shown the following table (Barnes, 2012, p. 885).

	Independent	**Dependent**
Fundamental	Mereological simples	Emergent entities
Derivative	Numbers	Complex objects, artefacts, etc.

The part of this matrix that is of concern here is the intersection of *fundamental* and *dependent*. That is, Barnes' theory of ontological emergence defines an emergent entity as one that is both fundamental and dependent. An entity is dependent on other entities if the dependent entity would cease to exist if the entities which gave rise to it ceased to exist. For example, the life of an individual human is dependent on the organs of the body (which are dependent upon the cells of the organ); the live human being would cease to exist if its organs ceased to exist. An entity is fundamental if there are no lower level entities – no parts of the fundamental entity – that could explain the existence of the entity. An emergent entity is something new, something that is distinct from the sum of its parts. The parts that give rise to the emergent entity – which the emergent entity is dependent upon – are not sufficient to explain the emergent entity's existence, therefore the emergent entity is fundamental.

Through this reasoning, if we consider societies[55] to be entities that emerge as a result of the interaction among human beings, as Sawyer and others suggest (K. R. Sawyer, 2005), then societies must be both fundamental and dependent. It seems clear that if human societies depend on humans for their existence, then the existence of human societies are

[55] For clarity, this discussion refers only to human societies.

dependent on the existence of humans. If human beings did not exist, human societies would not exist. On the other hand, the existence of humans, on their own, does not explain, a priori[56], the existence of society.[57]

How does ontological emergence relate to creativity? Before exploring this question, a definition of creativity is required.

3.3.7 Definition of Creativity

Progress in any area of research is aided by an established and broadly accepted lexicon. On the other hand, progress is hampered by the lack of broadly accepted definitions, since this results in a lack of clarity about exactly what it is that is being studied. As this section will reveal, this has been the case with creativity research for many years.

Over the past 70 years, many alternative definitions of creativity have been proposed. Each new definition claims to address one or more shortcomings of previous definitions, but the literature does not seem to be converging on a broadly accepted definition of creativity, despite some claims to the contrary. It has been reported by Parkhurst (1999) that in 1960, Repucci counted between 50 and 60 definitions of creativity in the literature. Shortly after, Rhodes (1961) wrote that “In time I had collected forty definitions of creativity and sixteen of imagination. The profusion was enough to give one the impression that creativity is a province for pseudo-intellectuals” (p. 306). By 1980, Welsch concluded, “the literature

---

[56] That is, without the benefit of experience or experimentation.

[57] It can be difficult to imagine observing a human being in isolation, while supressing our knowledge and understanding of societies, so it may be easier to consider observing an ant. A detailed study of an individual ant, or many individual ants in isolation, could never reveal to us anything about ant colonies and societies, without the benefit of experience or experimentation.

contains such a variance of definitional statements that the task of defining the concept of creativity is a challenging one" (p.3). In 2010, Hennessey and Amabile saw that things were not getting better. They noted that the "criteria for assessing persons or products may appear to be straightforward after decades of research. But appearances deceive. Debates surrounding definition and measurement continue to loom large" (p. 572).

Many creativity researchers see value in considering creativity from the perspective of the person, process, product or environment (place, or press), commonly referred to as the four Ps of creativity (Kozbelt et al., 2010). When viewed from the perspective of the four Ps, the creative person is one who comes up with creative products, while a creative process is one that is used to develop creative products, and a creative environment is one that supports the development of creative products. This perspective has resulted in most definitions of creativity focusing on the creative product. However, if creativity is to be defined in terms of creative products, the word *product* must also be defined. That is, what is it that can be evaluated for its creativeness? Also, unless the answer is built into a definition of creativity, we are left with the question of whose evaluation of the creativeness of a product or products should be accepted. Who are the arbitrators of creativity – who are the judges? Who selects and evaluates the performance of the judges? Who evaluates the selectors of the judges?

What has been called *Big C* versus *little c* creativity suggests some limitations on what can be evaluated for its creativity and by whom. Big C creativity is novel in a worldwide and historical context, has a lasting impact, and may result in a paradigm shift. Little c creativity is also referred to as personal, or everyday, creativity. The little c creative product is only novel from a personal point of view and generally does not have an impact beyond the individual and his or her immediate surroundings (J. C. Kaufman & Beghetto, 2009). From this perspective, individuals can self-judge little c creativity, while society at-large must be the judge of Big C creativity. However, creativity is not a dichotomy, being either big or little. Creativity exists on a continuum (Amabile, 1996), so the *Big C - little c* dichotomy is not much help in determining who is to judge products for their creativity.

Amabile (1977, 1996) developed the Consensual Assessment Technique (CAT) as a means of dealing with the lack of objective criteria for evaluating (judging) creative works. The CAT consists of a number of judges, familiar with the domain in question, independently evaluating and ranking creative products. While Amabile thought that judges only need to be familiar with the domain, in practice, most CAT evaluations have been performed with domain experts (Kaufman et al., 2008), presumably because other researchers always felt there was a need for the judges to be domain experts, rather than just familiar with the domain. The CAT led Amabile to define creativity as follows:

> A product or response is creative to the extent that appropriate observers independently agree it is creative. Appropriate observers are those familiar with the domain in which the product was created or the response articulated. Thus, creativity can be regarded as the quality of products or responses judged to be creative by appropriate observers, and it can also be regarded as the process by which something so judged is produced. (Amabile, 1996, p. 33)

The term "quality of the products or responses" hints at one of the main issues involved in defining creativity. That is, the confounding of skill and creativity. If an artist has a highly-creative idea but does not have sufficient skill to produce that idea well, it should not take away from the creativity of the idea. However, if the end product, and the quality of its production, are used to evaluate the creativity of the idea that was the impetus for the end product, poor quality production can be expected to have a negative effect on the judgment of the idea's creative merit. If someone writes a new piece of music which is then performed by someone else, is it not the writer whose creativity led to the new music. The person playing the music may well have exhibited a great deal of creativity in the interpretation of the original composition, but that is not necessary, the performer could just exhibit skill. If I come up with an idea for a new product and take it to an engineering firm to have detailed design drawings produced then send those drawings out to have the product produced, the creativity resides with my idea, regardless of how much skill may have been applied throughout the rest of the process.

A definition of creativity that is considerably shorter than Amabile's has come to be known as the *standard definition* of creativity. It consists of just two criteria[58] (Carson, 2010). The first of these criteria is relatively unambiguous, however, quite a list of synonyms are used in the literature for this first criterion, including novel, new, unique, and original. The second criteria is less clear, but the general idea is to differentiate creative novelty from "the word salad of a psychotic" Runco and Jaeger (2012, p. 92), or from the "the scribblings of a toddler who has just learned to hold a crayon" (Carson, 2010, p. 5), or to "exclude uncommon responses which are merely random, or which proceed from ignorance or delusion" (Barron, 1955, p. 479).[59] Thus, one form of the standard definition is something

---

[58] Carson uses the term *elements*, rather than *criteria*, however, it seems that most researchers (including Barron, 1955; Runco & Jaeger, 2012; Simonton, 2012), prefer the term criteria. This paper will keep with this preference for using the term *criteria*, except when quoting the writings of those who refer to them as *elements*.

[59] To be precise, Barron was referring to originality, not creativity, but his thinking, in this case, applies to creativity as well.

that is original and of value. This two criteria definition of creativity has been stated even more succinctly as *effective novelty* (Cropley, 1999).

Runco and Jaeger (2012) credit Stein (1953) with the being "the first to offer the standard definition in an entirely unambiguous fashion" (p. 95). Stein's definition of creativity begins with *novel* as the first criteria and "tenable or useful" as the second (Stein, 1953, p. 311). That is, Stein defines creativity as coming up with something that is novel and tenable or useful. Since Stein, many other words have occupied the place of the second criterion in various 'standard' definitions, including: appropriate, adaptive, relevant, compelling, useful, of value, effective, acceptable, and realistic. The two criteria have also formed the basis of more complex definitions. For example, Mednick's associative theory of the creative process led him to argue that creative thinking is the process of "forming of associative elements into *new* combinations which either meet specified requirements or are in some way *useful*" (1962, p. 221, emphasis added).

While many creativity researchers may agree that the standard definition of creativity requires both *uniqueness* and *usefulness* (or one of a number of synonyms) (Plucker et al., 2004), this definition leaves open to question the definition of the terms unique and useful (or any of the other words used to express the two criteria definition of creativity). Unique to whom? How unique does the creative work have to be? Useful to whom? How useful? Does being more useful make the product more creative? Does the creative product's creativeness diminish with time, as its uniqueness decreases? This definition also does not address the question of who is to judge creative works for these criteria (Runco & Jaeger, 2012). How should creative works be judged? And what, exactly, is a *product*? That is, what types of *things* can we evaluate for their creativeness? For example, Vernon (1989), identified "ideas, insights, restructurings, inventions, or artistic objects" (p. 94) as possible *creative products*, while Amabile's (1996) definition of creativity suggests that it is a "product or response" (p. 33) that may be evaluated for its creativeness.

Although Carson (2010), claims that "… there are two elements to the definition that virtually all of us who study creativity agree need to be present in the creative idea or product" (p. 5) and Runco and Jaeger (2012) state that "the standard view points to two criteria" (p. 95), this seems to be far from universally accepted. Some creativity researchers think a third criterion needs to be added to the definition. For example, Rhodes (1961) added *goal-oriented* while Boden (2004), thinks *surprise* should be added as a third criterion. Bruner (1979), on the other hand, feels *effective surprise* is a sufficient criterion all on its own, while Simonton (2012) proposes that we should follow the lead of the US patent office, which requires a patentable idea to be *new*, *useful*, and *non-obvious*. However, he suggests using *surprise and surprising* in place of *non-obvious* and *nonobviousness*, arguing that they are less awkward (2012).

Other researchers reason that determining whether something is creative depends on context and, therefore, this must form part of the definition. For example, Plucker, et al (2004), define creativity as "the interaction among aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context" (p. 90).

Weisberg (2015) argues that *value* should not be part of the definition because it is subjective, subject to change over time, and conflicts "with our common-sense understanding of the concept of creativity" (p. 111). Weisberg instead proposes a single criterion of *intentional novelty*. In a similar vein, Smith and Smith (2017) argue for a 1.5 criterion model of creativity to recognize that novelty is the primary requirement for creativity, but they want to downgrade the second part of the definition. They argue that a creative idea should not have to actually work to be considered creative, it should just hold the potential to be successful. In their words: "We need to judge creativity by the novelty and it's potential to be useful" (p. 182).

If Amabile (1996) is correct, that there are no objective criteria for creativity because it is and always will be subjective, then creativity stands with other hard-to-define concepts, such as beauty and pornography. The question of defining pornography has caused one US supreme court justice to state that "I know it when I see it" (US Supreme Court, 1964) while beauty has long been said to 'be in the eye of the beholder.' Could creativity simply be in the eye of the beholder? Is Torrance (1988) correct when he claims that "creativity defies precise definition" (p. 43)? Could creativity be another concept that is easy enough to recognize, but impossible to define? For the sake of creativity research, let's hope not. Without a clear definition of creativity, it is unclear how the body of creativity literature fits together, and it may hinder progress. That is, if each researcher is using his or her own definition, then each researcher's body of work stands alone, rather than contributing to an overall body of knowledge. If not based on a common definition, theories of creativity are not competing theories, to be discussed, debated, and advanced, they are separate and unique theories about entirely different phenomena (that is, about creativity defined as different phenomena).

3.3.8 Creativity as ontological emergence

Sawyer (1999), once looked closely at the relationship between creativity and emergence, noting that both are clearly linked with novelty. The other aspect of emergence that is consistent in almost all definitions is that the emergent entity or property is unexpected (S. Johnson, 2002; S. A. Kauffman, 1995). This part of a definition of emergence – something which is novel and unexpected – is essentially the same as the definition of creativity used by those who think surprise should form part of the definition. That is, among others, Boden (2004), Bruner (1979), and Simonton (2012). Although, to be precise, Bruner calls for *effective surprise* and Simonton's proposed definition requires the additional criteria of *useful*.

While Sawyer (1999) notes that creativity and emergence are congruent when it comes to novelty, he argues that they are not one and the same because a creative product must also be *appropriate*, *useful* or *valuable* in some way. His argument against "an emergent theory of creativity" is summarised as follows:

> Appropriateness requires us to explore how different higher level systems require and reward different degrees of emergent novelty. Thus an emergent theory of creativity must describe relations between levels of analysis. An emergent model of appropriateness would require a level above the level of emergent novelty, a higher level capable of judging the appropriateness of the novelty generated by the lower level. This higher level could also be a complex, emergent system (p. 461).

In other words, Sawyer is arguing that, for creativity and emergence to be equivalent, emergent entities must not only be novel, they must also be appropriate, useful, or valuable and there must be a higher-level entity to judge or reward that appropriateness.

On the other hand, Seidel and Greve (2017) have stated that "Innovation relies on emergence by definition" (p. 2). Clearly suggesting that creativity relies on emergence since innovation relies on creativity. However, this assumption of a definitional reliance is not sufficient to support the claim that emergence and creativity are the same thing. There are two straightforward ways to argue against Sawyer's conclusion: 1) to argue that a creative product does not have to be appropriate, useful, or valuable, or 2) to argue that emergent entities are appropriate, useful, and/or valuable, and either the appropriate higher-level entity is available to judge "the appropriateness of the novelty," or no such judgment is required.

The stage can be set for the second line of argument by noting that creativity can and does have degrees of usefulness or value. This is similar to Smith and Smith (2017) downplaying the *value* criteria in their 1.5 criteria model of creativity. In fact, they suggest that the creative output could have very little value in that it only has to have the potential to be successful. Creativity exists on a continuum, as argued by Amabile (1996), and as fits with our intuitive concept of creativity. While creativity can be non-existent, as when a product is an exact copy of another, it can also range from very minimal to creative work that is beyond our comprehension. That is, a product is still creative when it is minimally novel and when it is minimally useful or valuable. This just results in the product being minimally creative. However, it is not always clear what it takes to move from no creativity to minimal creativity. If someone were to take an existing product and change the colour from blue to green, is that *not creative*, or is it *minimally creative*?

Emergence, on the other hand, is not generally thought of in this way. But why not think of emergence in terms of degrees? Certainly there can be degrees of novelty and degrees of surprise/unexpectedness, the two criteria almost universally associated with emergence. Also, an emergent entity may have little value and end up being short-lived, but it was still emergent. Alternatively, an emergent entity may quickly diffuse throughout a population due to its great value. Both are emergent.

Thinking in terms of ontological emergence, does the emergence of a new entity not have value in and of itself? Doesn't an ontological-emergent have inherent value, at least in the sense that it is contributing to the evolutionary process, even though it may be just to rule out something that is not useful at the given time and place? Even if it does not prove to be adaptive and does not last long, is there not value in at least illustrating what does not work? It does not have to be very useful, or have much value, to be compared to a minimally creative product, just a small, minimal amount. As Smith and Smith (2017) have argued regarding a creative product, it only has to hold the "potential to be successful" (p.282). In scientific research, the value of the negative result has long been recognized (Smart, 1964; Dirnagl & Lauritzen, 2010), while years of management literature has challenged managers to celebrate failure (Birkinshaw & Haas, 2016; Hirsch, 2012; Peters, 1987). In biology, preadaptations are, in a sense, an initial failure in adaptation. A preadaptation[60] is a trait that may have no selective significance in its original environment but in a different environment comes to have selective significance (S. Kauffman, 2010). Commonly cited examples include bird feathers and the lungs of basal fish.

This concept of potential value being sufficient applies equally well to ontological emergence and creativity. This leads to the possibility of an ontological emergence theory of creativity and the conception that creativity and ontological emergence are the same thing.

Recalling the definition of ontological emergence, it is seen that, in order for these two concepts to be equivalent, a creative product must be fundamental and dependent. Something is fundamental when there are no lower level entities – no parts of the fundamental entity – that explain the existence of the entity. That is, it cannot be further broken down into constituent parts. Something is dependent if it would cease to exist if the entities giving rise to it ceased to exist. Is a creative product fundamental? It certainly could be defined in such a way, without departing in a significant way from many existing definitions yet providing a more concrete delineation of what is creative. For example, the

---

[60] Now frequently referred to as exaptation (Pievani & Serrelli, 2011).

idea of attaching a flaked stone chopping tool to the end of a piece of wood to create an axe *is* creative, because the idea of a stone axe is ontologically emergent in relation to the ideas *stone chopping tool* and *piece of wood.* A complete understanding of stone chopping tools and pieces of wood in no way leads to the idea of a stone axe, until someone puts the two ideas together for the first time. [61]

In this ontological emergence theory of creativity, there are two different types of creativity, yet with the self-similarity that is to be expected of complex adaptive systems. One type is the creativity of nature, which includes all physical forms of emergence and is the driver behind biological evolution. While also a part of the creativity of nature, the other type of creativity has its basis in cognition and includes all creative cognitive acts performed by humans and other animals. While there may well be a direct relationship between the two, the distinction will support progress in the study of creativity because it will focus study on creative thought, thus removing physical construction of creative products – and the inevitable confluence of skill with creativity that construction of physical products results in – from the equation.[62] However, it is these two forms of creativity together that are the equivalent of ontological emergence.

To elaborate, in cognitively-based creativity, it is always the *idea* that is considered creative. Putting the idea into practice – creating the physical product – is something that

---

[61] In fact, the idea was so creative that it took approximately one million years for this revolutionary idea to result in the evolution of the stone tool (Larick & Ciochon, 1996).

[62] As an initial hypothesis, it seems that the cognitive form of creativity is likely a subset of the physical, nature-based form of creativity, with the connection being the physical basis of cognition, if there is such a thing.

requires some degree of skill, not creativity. While putting the idea into practice will inevitably require additional creativity – as problems are encountered and solved – the creative part will consist of bringing together the right ideas, resulting in the emergence of a creative idea. This addresses a major drawback of the CAT – the conflation of skill with creativity. Both skill and creativity may be required in order to have a product that is recognized as creative, but they are separate and distinct abilities. A person with a highly-creative idea can hire a highly-skilled person, who is only marginally-creative, to merely execute the instructions of the highly-creative person, and a product that is recognized as creative will be the result. The reverse does not hold true. That is, if a marginally-creative but highly-skilled person hires a highly-creative person (or another marginally-creative but highly-skilled person, for that matter) to merely execute their instructions, we should not expect the result to be a product that is recognized as creative.

Seeing products as ranging from marginally to highly-creative should be the popular, or lay-person, interpretation of creativity. Creativity researchers should recognize the inherent confluence of creativity and skill and constrain research to creative cognition. Thus, the four Ps of creativity should be interpreted as follows:

- A creative product is one that has been skillfully produced from a creative idea.
- A highly-creative person is one who has highly-creative ideas.
- A creative process is one which yields highly creative ideas.
- A creative environment (press or place) is one which is conducive to highly creative ideas.

To reiterate, for creativity to be defined as ontological emergence, creative ideas must be fundamental. The new idea must be fundamental – not able to be broken down into parts that, on their own, would predict or make obvious the creative idea a priori. That is, the creative idea must be non-obvious. On their own, a flaked stone chopping tool and a piece of wood do not predict the axe any more than knowledge of the cells in our bodies predict life.

The next step in assessing creativity as ontological emergence is to decide if a creative product is dependent. It seems clear that the answer is yes. A creative idea is dependent on the two or more ideas that were brought together for the creative idea to emerge. The idea of a stone axe is dependent on the ideas of a piece of wood and a flaked stone chopping tool (or some reasonable alternatives) for its existence. If those ideas could somehow be removed, the idea of a stone axe could not exist.

So, creativity can be defined in a way that is consistent with ontological emergence. But what about creativity being appropriate, useful and/or valuable? Is creativity-as-ontological-emergence appropriate, useful and/or valuable? Are emergent entities appropriate, useful and/or valuable?

Life is considered by many to be an emergent property that arises from the combination of molecules (Holland, 2012). If this is true, then the concept of emergence is fundamental to life itself. And if emergence is largely responsible for evolution, as envisioned by Stuart Kauffman (2010), then not only is life emergent, but continuing life is also an ongoing process of emergence. With every agent continually adapting to the constant changes in other agents and its environment, emergence is part of the evolutionary process. That is, evolutionary adaptations are emergent. Without this constant adaptation and evolution, life dissipates and dies (S. A. Kauffman, 1995). This is the creative process, whether driven by human cognition or by biology; adaptive evolution is emergent, adaptive evolution is creative (when employing the ontological-emergence definition of creativity).

It is proposed that when the adaptive evolution is scientific, technological, or cultural – anything that is based on ideas – then the emergent idea is creative in the cognitive sense. Thinking in terms of creativity being fundamental to all life, as biological emergence is, then combining entities in new ways until something novel and unexpected emerges is always appropriate. Even if the new entity does not last, if it is part of an overall evolutionary framework, then trying these new things to determine what works and what doesn't in the current context is appropriate. There is value in learning what doesn't work. The same applies to the ontologically emergent creativity in science, technology and culture. The same evolutionary process takes place in each of these areas. All emergent ideas have inherent value, even if that value is just in demonstrating what does not work in a particular environment at a particular time. The emergent/creative idea merely must have the potential to work, or the potential to have value, or the potential to be adaptive.

However, this is where the closely related concept of innovation comes into play. To determine if a creative idea with potential value has any actual value, the idea must be put into practice. It must be given form, or given life in some way, and allowed to flourish – allowed to diffuse as far as it is able to throughout a potential user base. Many readers can probably remember a creative idea they have had that they imagined might have had some value – if only someone took it and commercialized it. Without the effort to give form to the idea, the value was never realized. Your creative idea had unrealized potential value.

Regarding Sawyer's claim that there would have to be a higher level to evaluate the creative product if creativity and emergence were equivalent, the higher-level system may judge the degree of creativity by how far it diffuses, but there is creativity in an instance of one. This is what can be considered minimally-creative (or, the most minimally-creative), an instance of one that does not spread. But it is greater than zero and, therefore, cannot be considered non-creative. To be fair, Sawyer also noted that "Appropriateness requires us to explore how different higher level systems require and reward different degrees of emergent novelty" (R. K. Sawyer, 1999, p. 461). When creativity is defined as ontological emergence, this reward is a judgement on the *degree* of creativity, not on the existence of creativity. When a fundamental, dependent idea emerges, it *is* creative. *How* creative it is, is then dependent on the interplay of the two criteria – how novel and how useful. Being a product of the two means that either minimal novelty or minimal usefulness will result in minimal creativity.

What does the foregoing mean in terms of a definition of creativity? This is the resulting *emergence definition of creativity*: Creativity is the result of two or more entities being combined, resulting in a new and unexpected entity that is both fundamental and dependent. That is, a complete understanding of the initial entities does not result in an understanding of the new entity and the new entity cannot exist without the initial entities. In all cognitively-based creativity, the entities referred to are ideas (including knowledge, conceptions and perceptions), while the act of putting such ideas into practice is either craft[63], if the end product is a cultural one, or innovation if it is not.

3.3.9 Conclusions, Implications and Future Work

This ontological emergence theory of creativity is not without its challenges. It may not always be clear when a new idea that emerges from the combination of two other existing ideas could or could not have been predicted by studying the two ideas in isolation.[64]

---

[63] For the purposes of this definition of creativity, craft is defined as, the output resulting from the act of putting a creative idea into practice when the output is for primarily aesthetic or cultural reasons.

[64] Recall that an idea is an entity that is strictly cognitive.

It also does not solve the problem of subjectivity when determining the degree of creativity and it may not fully solve the problem of conflating skill with creativity since many creative ideas must be given physical form if we are to be able to assess their creativity. However, explaining this definition of creativity to those judging creativity would help minimize this concern.

While there are bound to be some details left to be worked out with this proposed view of creativity, it does present a new framework for analyzing creativity, which appears to be internally consistent. It also seems to be consistent with the results of creativity research. This new perspective could help solve what appears to be a logjam: reaching an agreement regarding the definition of creativity. This creativity-as-ontological-emergence perspective also provides an excellent point-of-entry for a new complexity theory of creativity, which would provide a more holistic view and model of creativity. Successfully arguing and concluding that creativity and emergence are one and the same thing should provide an impetus to critically examine the other characteristics of complex adaptive systems to see if there is further congruence with the growing body of creativity research. If creativity is the same thing as emergence, and if emergence is a feature of complex adaptive systems, then creativity is a feature of complex adaptive systems. This changes the research questions surrounding creativity from ones such as 'how can we enhance creativity?' to 'what parameters of a complex adaptive system can be adjusted to increase the probability of creative outcomes?'

Bibliography

Amabile, T. M. (1977). *Effects of extrinsic constraint on creativity*. Stanford University. Retrieved from http://search.proquest.com/docview/302845439?

Amabile, T. M. (1996). *Creativity in context: Update to the social psychology of creativity*. Boulder, CO: Westview Press.

Anderson, P. W. (2008). Complexity: 5 questions. In C. Gershenson (Ed.) (pp. 5–8). [S.l.]: Automatic Press.

Bar-Yam, Y. (1997). *Dynamics of Complex Systems*. Addison-Wesley.

Barnes, E. (2012). Emergence and Fundamentality. *Mind*, *121*(484), 873–901.

Barron, F. (1955). The disposition toward originality. *Journal of Abnormal Psychology*, *51*(3), 478–485.

Bechtel, W., & Richardson, R. C. (1998). Vitalism. In E. Craig (Ed.), *Routledge Encyclopedia of Philosophy*. London, UK: Routledge. Retrieved from https://mechanism.ucsd.edu/teaching/philbio/vitalism.htm

Birkinshaw, J., & Haas, M. (2016). Increase Your Return on Failure. *Harvard Business Review*, (May), 88–93. Retrieved from https://hbr.org/2016/05/increase-your-return-on-failure

Boden, M. A. (2004). *The Creative Mind: Myths and Mechanisms* (Second). New York, NY: Routledge.

Bruner, J. S. (1979). *On Knowing: Essays for the Left Hand* (Expanded). Cambridge, MA: Belknap Press of Harvard University Press.

Buxbaum, R. E. (2013). Heisenberg joke and why water is wet. Retrieved August 19, 2018, from http://www.rebresearch.com/blog/heisenberg-joke-answers-why-is-water-wet/

Camazine, S., Deneubourg, J. L., Franks, N. R., Sneyd, J., Bonabeau, E., & Theraula, G.

(2003). *Self-organization in Biological Systems*. Princeton, NJ: Princeton University Press.

Carson, S. (2010). *Your creative brain: Seven steps to maximize imagination, productivity, and innovation in your life*. San Francisco, CA: Wiley.

Coghlan, A. (1997). What really makes water wet? *New Scientist*, *153*(2069), 21.

Colin, T. (2017). Analyzing Ambiguity in the Standard Definition of Creativity. *AVANT. The Journal of the Philosophical-Interdisciplinary Vanguard*, *VIII*(Special), 25–34. https://doi.org/10.26913/80s02017.0111.0003 LK - https://unb.on.worldcat.org/oclc/7220188419

Corning, P. A. (2002). The re-emergence of ?emergence?: A venerable concept in search of a theory. *Complexity*, *7*(6), 18–30.

Cropley, A. J. (1999). Creativity and cognition: Producing effective novelty. *Roeper Review*, *21*(4), 253–260. https://doi.org/10.1080/02783199909553972

Dirnagl, U., & Lauritzen, M. (2010). Fighting publication bias: introducing the Negative Results section. SAGE Publications Sage UK: London, England.

Guilford, J. P. (1950). Creativity. *American Psychologist*, *5*(9), 444–454. https://doi.org/10.1037/h0063487

Halvorson, H. (2015). What Does Quantum Mechanics Suggest About Our Perceptions of Reality? Retrieved August 19, 2018, from https://www.bigquestionsonline.com/2015/02/24/what-does-quantum-mechanics-suggest-about-our-perceptions-reality/

Hawking, S. (2000). I think the next century will be the century of complexity. Retrieved November 13, 2016, from http://www.complexsys.org/downloads/whatiscomplexity.pdf

Hennessey, B. A., & Amabile, T. M. (2010). Creativity. *Annual Review of Psychology*, *61*, 569–

598. https://doi.org/10.1146/annurev.psych.093008.100416

Hirsch, E. (2012). The Paradox of Design Entrepreneurship: Are You a Risk Voyeur? *Design Management Review*, *23*(3).

Holland, J. H. (2012). Signals and boundaries: Building blocks for complex adaptive systems. Cambridge, Mass.: MIT Press. Retrieved from http://public.eblib.com/choice/publicfullrecord.aspx?p=3339466

Huber, J. (1991). *Macro-micro linkages in sociology. American Sociological Association presidential series*. Newbury Park, Calif.: Sage Publications.

Johnson, N. (2009). *Simply Complexity: A Clear Guide to Complexity Theory*. Oneworld Publications.

Johnson, S. (2002). *Emergence : the connected lives of ants, brains, cities, and software*. New York, NY: Simon & Schuster.

Kauffman, S. (2010). Reinventing the Sacred : a New View of Science, Reason, and Religion. New York: Perseus Books Group. Retrieved from http://public.eblib.com/choice/publicfullrecord.aspx?p=479044

Kauffman, S. A. (1995). *At home in the universe: The search for laws of self-organization and complexity*. New York, NY: Oxford University Press.

Kaufman, J. C., & Beghetto, R. A. (2009). Beyond Big and Little: The Four C Model of Creativity. *Review of General Psychology*, *13*(1), 1–12. https://doi.org/http://dx.doi.org.proxy.hil.unb.ca/10.1037/a0013688

Kim, J. (2008). The Nonreductivist's Troubles with Mental Causation. In *Emergence : Contemporary Readings in Philosophy and Science*. The MIT Press.

Kozbelt, A., Beghetto, R. A., & Runco, M. A. (2010). Theories of creativity. In J. C. Kaufman & R. J. Sternberg (Eds.), *The Cambridge Handbook of Creativity* (pp. 20–47).

Laplace, P. S. (1902). *A philosophical essay on probabilities*. (F. W. Truscott & F. L. Emory, Eds.) (Translated). London, UK: Chapman and Hall. Retrieved from https://bayes.wustl.edu/Manual/laplace_A_philosophical_essay_on_probabilities.pdf

Larick, R., & Ciochon, R. (1996). African Emergence and Asian Dispersals of Homo. *American Scientist*. Retrieved from http://www.jstor.org/stable/29775783

Lewis, D. K. (1986). *On the plurality of worlds*. Oxford, UK ; B. Blackwell.

Lobo, I. (2008). Biological complexity and integrative levels of organization. https://doi.org/10.1126/science.101.2618.209

Mitchell, M. (2009). *Complexity: A guided tour*. Oxford, UK: Oxford University Press.

Niño El-Hani, C., & Pihlström, S. (2002). EMERGENCE THEORIES AND PRAGMATIC REALISM. *Essays in Philosophy*, *3*(2). Retrieved from http://www.helsinki.fi/science/commens/papers/emergentism.pdf

Nunez, P. L. (2016). *The New Science of Consciousness: Exploring the Complexity of Brain, Mind, and Self*. Amherst, NY: Prometheus Books.

O'Connor, T., & Wong, H. Y. (2015). Emergent Properties. In Stanford University. & Center for the Study of Language and Information (Eds.), *Stanford encyclopedia of philosophy*. Stanford University. Retrieved from https://plato.stanford.edu/entries/properties-emergent/

Page, S. E. (2009). *Understanding Complexity*. Chantilly, Va.: The Teaching Company.

Parkhurst, H. B. (1999). Confusion, lack of consensus, and the definition of creativity as a construct. *The Journal of Creative Behavior.*, *33*(1), 1.

Peters, T. (1987). *Thriving on Chaos: Handbook for a Management Revolution*. Toronto, ON: Random House.

Pievani, T., & Serrelli, E. (2011). Exaptation in human evolution: how to test adaptive vs exaptive evolutionary hypotheses. *JASs Invited Reviews Journal of Anthropological Sciences*, *89*, 9–23. https://doi.org/10.4436/jass.89015

Plucker, J. A., Beghetto, R. A., & Dow, G. T. (2004). Why isn't creativity more important to educational psychologists? Potentials, pitfalls, and future directions in creativity research. *Educational Psychologist*, *39*(2), 83–96. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=13310450&site=ehost-live&scope=site

Raggett, S. (2012). *Consciousness, Biology and Fundamental Physics*. AuthorHouse UK.

Rhodes, M. (1961). An analysis of creativity. *The Phi Delta Kappan*, *42*(7), 305–310. Retrieved from http://www.jstor.org./stable/20342603

Robinson, H. (2016). Dualism. In Stanford University. & Center for the Study of Language and Information (Eds.), *Stanford encyclopedia of philosophy*. Stanford University. Retrieved from https://plato.stanford.edu/entries/dualism/

Runco, M. A., & Jaeger, G. J. (2012). The standard definition of creativity. *Creativity Research Journal*, *24*(1).

Sawyer, K. R. (2005). *Social Emergence: Societies as Complex Systems*. New York, NY: Cambridge University Press.

Sawyer, K. R. (2012). *Explaining Creativity: The Science of Human Creativity* (2nd ed.). New York, NY: Oxford University Press.

Sawyer, R. K. (1999). The emergence of creativity. *Philosophical Psychology*, *12*(4), 447–469. https://doi.org/10.1080/095150899105684

Schaffer, J. (2003). Is There a Fundamental Level? *Noûs*, *37*(3), 498–517.

Seidel, M.-D., & Greve, H. R. (2017). Emergence. Bingle, UK: Emerald Publishing Limited.

Simonton, D. K. (2012). Taking the U.S. Patent Office Criteria Seriously: A Quantitative

Three-Criterion Creativity Definition and Its Implications. *Creativity Research Journal*, *24*(2–3), 97–106. https://doi.org/10.1080/10400419.2012.676974

Smart, R. G. (1964). The importance of negative results in psychological research. *Canadian Psychologist/Psychologie Canadienne*, *5*(4), 225.

Smith, J. K., & Smith, L. F. (2017). The 1.5 Criterion Model of Creativity: Where Less Is More, More or Less. *Journal of Creative Behavior*, *51*(4), 281–284.

Stein, M. I. (1953). Creativity and Culture. *The Journal of Psychology*, *36*(2), 311–322. https://doi.org/10.1080/00223980.1953.9712897 LK - https://unb.on.worldcat.org/oclc/4652930221

Stoljar, D. (2015). Physicalism. In Stanford University. & Center for the Study of Language and Information (Eds.), *Stanford encyclopedia of philosophy*. Stanford University. Retrieved from https://plato.stanford.edu/entries/physicalism/

Torrance, P. E. (1988). The nature of creativity as manifest in its testing. In R. J. Sternberg (Ed.), *The nature of creativity: Contemporary psychological perspectives1* (pp. 43–75). New York, NY: Cambridge University Press.

US Supreme Court. (1964). Jacobellis v. Ohio :: 378 U.S. 184. Retrieved October 6, 2018, from https://supreme.justia.com/cases/federal/us/378/184/#197

Vernon, P. E. (1989). The Nature-Nurture Problem in Creativity. In J. A. Glover & R. R. Ronning (Eds.), *Handbook of Creativity. Perspectives on Individual Differences* (pp. 93–110). Boston, MA: Springer. Retrieved from https://doi.org/10.1007/978-1-4757-5356-1_5%0A

Weber, B. (2011). Life. In Stanford University. & Center for the Study of Language and Information (Eds.), *Stanford encyclopedia of philosophy*. Stanford University. Retrieved from https://plato.stanford.edu/entries/life/

Weinberg, S. (1987). Newtonianism, Reductionism and the Art of Congressional Testimony. *Nature*, *330*(6147), 433.

Weisberg, R. W. (2015). On the Usefulness of "Value" in the Definition of Creativity. *Creativity Research Journal*, *27*(2), 111–124. https://doi.org/10.1080/10400419.2015.1030320

Welsch, P. K. (1980). *The Nurture of Creative Behavior in Educational Environments: A Comprehensive Curriculum Approach*. Michigan State University.

4 Discussion, Conclusions and Future Work

This dissertation addresses the research questions:

- How would a complexity theory of creativity explain the paradoxes revealed in creativity research?
- In what ways does diffusion of innovation data support a new complexity perspective of creativity and innovation?
- What definition of creativity emerges from a complexity theory of creativity?

These questions, their answers, and the discussion throughout this work have been embedded within the larger thematic context of developing an overarching complexity theory of creativity. Due to the scope of this task, this dissertation is exploratory, setting the stage for a comprehensive, internally consistent complexity theory of creativity that is consistent with current complexity science theory, is consistent with all known creativity research results, and that also has good explanatory power for discrepancies seen in creativity research (that is, paradoxes; see "The Order – Chaos Definition of Creativity" article in this dissertation for more on this topic). This larger thematic context is also the basis of this dissertation's primary research questions:

- What support is there for understanding creativity as a characteristic of complex adaptive systems?
- What parallels are there between major characteristics of complex adaptive systems and the results of creativity research?

A few key topics will be reviewed here to provide context for the summary and discussion to follow.

4.1 Definition of Creativity, Innovation, and Complex Adaptive Systems

This dissertation began by using a broadly accepted definition of creativity: the generation of something which is original and of value or adaptive. A detailed account of the definition of creativity was left out of the literature review in order to allow this topic to be explored in more detail in the third article, "The Ontological Emergence of Creativity." In a similar fashion, the article "The Complex Adaptive Process of Innovation Diffusion" avoided an in-depth discussion of a definition of innovation and instead used Rogers' (2003) definition: "an idea, practice, or object that is perceived as new by an individual or another unit of adoption" (p. xx). This was partly because the article was addressing Roger's decades-long work on the diffusion of innovation but was also to allow this definition to be resolved along with the definition of creativity in *The Ontological Emergence of Creativity*.

The definition of creativity that emerged from this research effort and was included in *The Ontological Emergence of Creativity* is:

> Creativity is the result of two or more entities being combined, resulting in a new and unexpected entity that is both fundamental and dependent. That is, a complete understanding of the initial entities does not result in an understanding of the new entity and the new entity cannot exist without the initial entities. In all cognitively-based creativity, the entities referred to are ideas (including knowledge, conceptions and perceptions), while the act of putting such ideas into practice is either craft[65], if the end product is a cultural one, or innovation if it is not. (p. 336)

[65] For the purposes of this definition of creativity, craft is defined as, the output resulting from the act of putting a creative idea into practice when the output is for primarily aesthetic or cultural reasons.

This could be written more succinctly as: Creativity is the ontological emergence (fundamental, yet dependent) of an idea. Innovation is the act of putting a creative idea into practice.

Also, in *The Ontological Emergence of Creativity*, complexity was defined as follows:

> a complex adaptive system is any set of diverse, interdependent agents that interact with and adapt to each other and their environment, thereby resulting in a new, emergent entity, entities, or agents that could not have been predicted from complete knowledge of the agents and their relationships.. (p. 313)

4.2 Research Questions and Conclusions

From the perspective of this dissertation, each article addresses one of the research questions listed above. However, as each article must stand on its own, without the benefit of a significant literature review and this concluding chapter, at the level of the article the questions addressed were different.

The Order – Chaos Dynamic of Creativity addresses the questions: Creativity: mysterious, contradictory, or paradoxical – which, if any, is it? Why? What could the answer tell us about creativity theory? How should future creativity research take this into account? On the other hand, the article also addressed the dissertation-level question: How would complexity theory explain the paradoxes revealed in creativity research?

The conclusion: Creativity is mysterious, contradictory, and paradoxical because creative people tend to "move dynamically along the continua implied by those paradoxes" (p. 201). "Creative people, it seems, tend to find a middle way, not by operating at a mid-point along a continuum, but by operating at and blending two more extreme positions. This is consistent with complexity theory, particularly the *order-chaos dynamic* characteristic of complex adaptive systems" (p. 195).

The implication of this research is that highly creative people move along various personality dimensions more than less creative people. This could provide a unique, new means of assessing creative potential.

The Complex Adaptive Process of Innovation Diffusion addresses the question: Are diffusion of innovations data normally distributed, or do they fit a power law distribution, or other common distribution? From the higher-level, dissertation perspective, the article addresses the question: In what ways does diffusion of innovation data support a new complexity perspective of creativity?

The conclusion: The diffusion of innovation data sets analyzed did not show support for concluding that they came from a normally distributed population, from a power law distributed population, or from a population conforming to any common distribution type. A complex adaptive systems model of creativity and innovation predicts that the diffusion of innovations will exhibit unpredictable diffusion profiles. That is, if creativity and innovation are characteristics of complex adaptive systems, we should expect to see unpredictable diffusion curves, as exhibited by the data analyzed.

The implication of this research is that it is not possible to predict the diffusion of any individual innovation and, therefore, innovations should be managed as portfolios, in a manner similar to venture capitalists.

The Ontological Emergence of Creativity addresses the question: In what ways could creativity and emergence be considered the same constructs? What definition of creativity emerges when it is considered to be ontologically emergent? The article serves to address the dissertation-level question: What definition of creativity emerges from a complexity theory of creativity?

The conclusion: The article argues that creativity and emergence are the same constructs when emergence is defined as ontological (fundamental yet dependent) emergence. This provides what could prove to be a necessary condition for the development of a comprehensive, internally consistent model of complexity that explains creativity. When creativity is considered to be ontologically emergent, the following definition emerges (this s the same definition as presented previously in this chapter):

> Creativity is the result of two or more entities being brought together and resulting in a new and unexpected entity that is both fundamental and dependent. That is, a complete understanding of the initial entities does not result in an understanding of the new entity and the new entity cannot exist without the initial entities. In all cognitively-based creativity, the entities referred to are ideas (including knowledge, conceptions and perceptions), while the act of putting such ideas into practice is either craft, if the end product is a cultural product, or innovation if it is not. (p. 336)

The implication of this work is that, when creativity is defined in terms of complex adaptive systems, there is a natural, self-supporting fit between the two concepts. This could lead to new ways of thinking about and researching creativity.

4.3 Future Research

The research addressed in the three articles revealed many lines of potential future research. *The Order – Chaos Dynamic of Creativity* suggested that:

- Research should be undertaken to determine if measures of personality traits exhibit dynamic movement, as predicted by an order-chaos-dynamic theory of personality. That is, perhaps what has been reported as repeatability error is not all a result of repeatability errors but are, instead, changes in personality characteristics over time that we should expect people to exhibit.

- A prediction of the order-chaos-dynamic theory of creativity is that people who are more creative will exhibit a greater range of movement, and may exhibit greater frequency of movement, along various personality dimensions, than those who are less creative. Research should be undertaken to determine if this is the case. If so, this may lead to a better tool for discovering highly-creative individuals.
- Research to determine if multiple dimensions of adversarial networks would increase the 'creativity' of AI systems is warranted.
- Research to determine if the most creative organizations are those that dynamically adapt along the continua of: centralized control, power differentials, information flow, diversity, number of interconnections, richness of interconnections, and contained anxiety, could help to better understand creativity and innovation in organizations. That is, it may be possible that Stacey's (1996) model of complexity and creativity in organizations could be operationalized by combining it with the order-chaos-dynamic theory of creativity.
- In a similar vein to the creativity of organizations mentioned in the previous point, creative groups are more predicted to exhibit more dynamic movement along various continuums. Research into what continuums apply to groups, versus individuals or organizations could be useful in many situations, including in the classroom where creativity is often group-based.

The Complex Adaptive Process of Innovation Diffusion article suggested the following future work:

- The research should be extended to different products and different geographies. Patterns should be looked for in different product types, diffusion channels, network effects, small-world network parameters, and innovation characteristics (relative advantage, compatibility, complexity, triability, and observability).
- A complex adaptive systems approach to the diffusion of innovation, particularity the application of small-world networks to this topic, opens up many lines of inquiry, including the application of an order-chaos dynamic to the social categories in Rogers' model. Should be expect change in these categories from one innovation to the next?

It would also be instructive to build agent-based computer models of small-world networks incorporating various adopter characteristics (see Rogers, 2003), while testing for effects on the rate and extent of diffusion from changes in innovation characteristics and adopter characteristics.

The main suggestion for future research arising out of *The Ontological Emergence of Creativity* is one that arose in the other articles as well. That is, the work involved in each of the articles should be incorporated into a more comprehensive complexity theory of creativity.

Together, the results of the research presented in the three articles presents a strong argument for there being a connection between creativity and complex adaptive systems, and the need for a more comprehensive complexity theory of creativity. A proposed model and

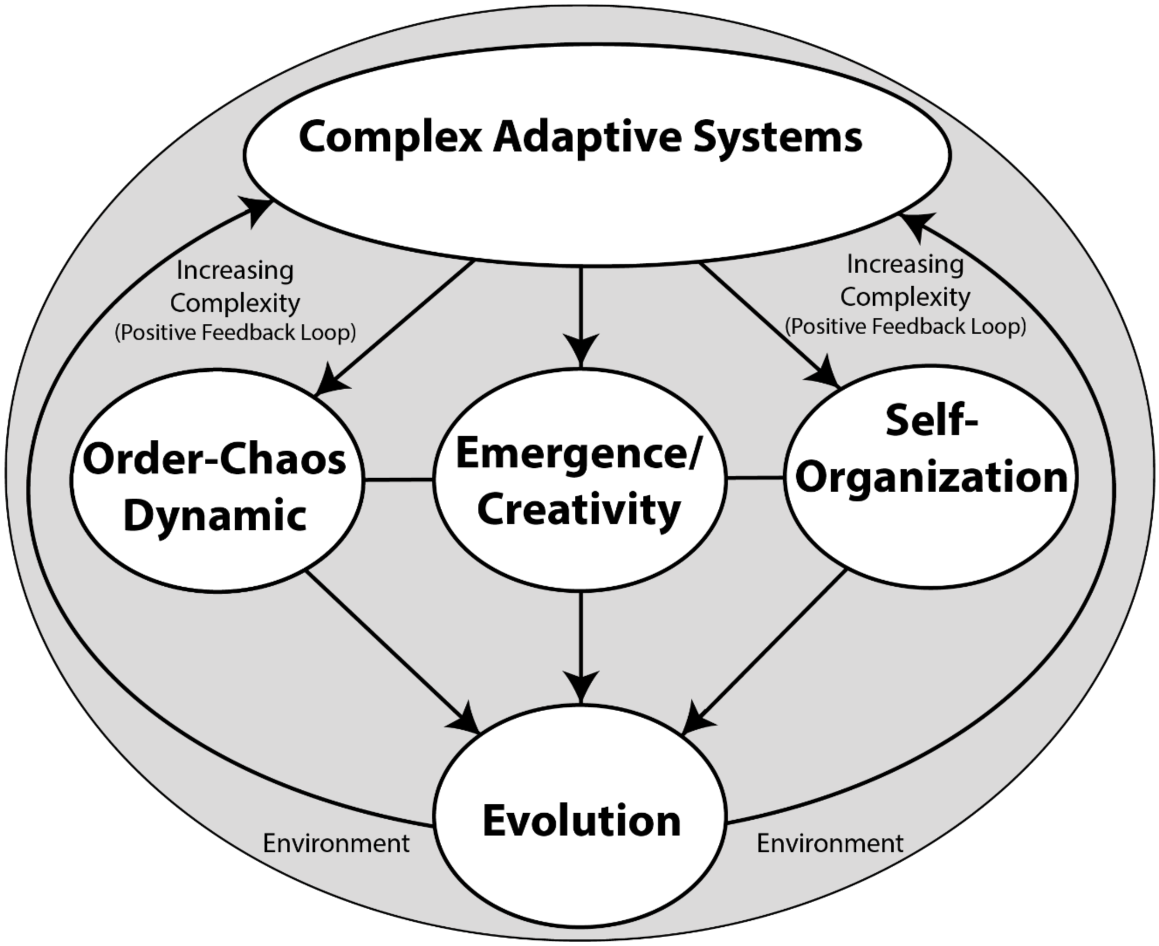


Figure 23: Complex Adaptive Systems Model of Creativity

framework for future research is presented in Figure 23. This model incorporates the subjects of the three articles. *The Ontological Emergence of Creativity* is represented by the oval in the middle 'Emergence/Creativity' while *The Order -Chaos Dynamic of Creativity* is represented by the oval to the left 'Order-Chaos Dynamic (Exploration-Exploitation)'. Perhaps not as immediately apparent is that the oval to the right, 'Self-Organization (Small-World Networks; Order for Free)' represents the research presented in the article *The Complex Adaptive Process of Innovation Diffusion.* In the article, it is suggested that diffusion of innovations takes place through social networks, which can be represented as small-world networks. Further, it is hypothesized here that small-world networks are a type of self-organization. Self-organization is a characteristic of complex adaptive systems that Kauffman (1995) refers to as "order for free."

This model is based on the argument that these three things; the order – chaos dynamic, emergence/creativity, and self-organization, are characteristics of complex adaptive systems. That is, the interaction and adaptation of a set of diverse, interdependent agents (a complex adaptive system) results in these three characteristics. Further, in order to bring in other characteristics of complex adaptive systems (S. A. Kauffman, 1995), it is proposed that these three characteristics lead to evolutionary action and that evolution results in a positive feedback loop that serves to increase the degree of complexity in the complex adaptive system. In this proposed model, which may provide a useful framework for future research, the environment (everything outside of the complex adaptive system) has an impact on all parts of the system. As suggested by this model, the other characteristics of complex adaptive systems are not part of the evolutionary/positive-feedback-loop framework. Those characteristics include, but may not be limited to, power-law distributions (and their associated fat-tailed behaviour), sensitive dependence on initial conditions (that is, these systems may, in theory, be deterministic, yet they are unpredictable), and self-similarity (patterns are expected but specifics are not predictable). If this is found to be correct, then these characteristics are merely by-products of complex adaptive systems, rather than integral features of this evolutionary/complex adaptive system framework. It is conceivable that this model could be tested against all forms of evolution: biological, cultural, scientific, and technological.

Is one of the keys to the mysteries of complex adaptive systems self-organization? The self-organization of complex adaptive systems seems to result in small-world network topologies, but is this always the case? Are small-world networks nature's way of addressing the need for dynamic exploration-exploitation optimization? Is bounded rationality (Simon, 1972) a characteristic of this optimization? Are our brains small-world networks that act as association hunting agents, constantly processing our perceptions to find which memories they have the strongest association with, in order to link new experiences into our existing schema – our existing small-world network. Could it be that our unconscious mind is constantly at work doing this – both finding the best associations for our new experiences and upgrading other memories – to stronger associative links? Might this be the cause of dreams; that is, are dreams merely what we experience as our subconscious tests out new associations – new connections in our own small-world network? Perhaps when a strong enough associative link is found, a cascade of neurochemicals is released, helping to both strengthen the synaptic linking and bringing the linkage to conscious awareness? Perhaps the flood of neurochemicals acts as a knock on the door to our consciousness? It might be loud, or quiet, depending on the strength of the association. But could there be a threshold level? Perhaps how closely we listen for these knocks at the door depends on our openness to experience, giving rise to the ah-ha moment when the knock is loud enough and our attention threshold low enough? Perhaps when the knock is too quiet to rise to the level of our conscious awareness, it is felt at the level of intuition? These are exciting questions, all based on my intuition, yet each is related to a rich and broad literature. Is it possible to relate all of these areas of study to one model? I can only hope that future research will shed some light on these questions, allowing our understanding of creativity to grow from an intuition, to a conscious understanding.

Next steps in further developing the model include further exploring the role of small-world networks in the self-organization that is characteristic of complex adaptive systems; exploring how the three characteristics discussed (order-chaos dynamics, emergence, and self organization) relate, interact and lead to evolution; researching the concept of evolution as a positive-feedback loop which tends to increase complexity; and elaborating on the role of the environment in this model.

Bibliography[66]

Kauffman, S. A. (1995). *At home in the universe: The search for laws of self-organization and complexity*. New York, NY: Oxford University Press.

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). New York, NY: Free Press.

Simon, H. A. (1972). Theories of Bounded Rationality. In C. B. McGuire & R. Radner (Eds.), *Decision and Organization* (pp. 161–176). North-Holland Publishing Company. Retrieved from http://innovbfa.viabloga.com/files/Herbert_Simon___theories_of_bounded_rationality___1972.pdf

[66] This bibliography is for chapter 5 and the introduction to chapter 4 only. There are separate bibliographies for each article and for the first three chapters.

Glossary

Agent: an entity that interacts with other agents and its environment and adapts its behaviour based on those interactions.

Complex Adaptive System: a complex adaptive system is any set of diverse, interdependent agents that interact with and adapt to each other and their environment, thereby resulting in a new, emergent entity, entities, or agents that could not have been predicted from complete knowledge of the agents and their relationships.

Complex Physical System: "arrays of elements, in which interactions typically depend only on effects propagated from nearest neighbours" (Holland, 2012, p. 6)

Craft: The output resulting from the act of putting a creative idea into practice when the output is for primarily aesthetic or cultural reasons.

Creativity (simple): the generation of something which is original and of value or adaptive.

Creativity (complex): Creativity is the result of two or more entities being brought together and resulting in a new and unexpected entity that is both fundamental and dependent. That is, a complete understanding of the initial entities does not result in an understanding of the new entity and the new entity cannot exist without the initial entities.

Creativity (abbreviated complex): the ontological emergence (fundamental, yet dependent) of an idea.

Dependence: See ontological dependence.

Dualism: the theory that reality consists of more than just the physical; that non-physical entities exist.

Element: the smallest unit that anything may be broken down to (see fundamental).

Emergence: the arising of a new entity, entities, or agents, as a result of the interaction of a set of diverse, interdependent agents that adapt to each other and their environment. The new entity, entities, or agents could not have been predicted from a from a complete knowledge of the agents and their relationships.

Entity: something that has its own existence, separate from, but not necessarily independent of, the elements which make it up, or from which it arose. An entity may be concrete or abstract, material or immaterial. Specifically, an entity does not have to exist physically.

Fat-tailed behaviour: in a system means there is a greater likelihood of extreme events than there is in a system that follows a Gaussian distribution (see self-organized criticality).

Fundamental: the level at which entities cannot be further broken down into constituent parts.

Innovation (verb): the act of putting a creative idea into practice when the output is not primarily aesthetic or cultural.

Innovation (noun): the output of the act of innovating.

Locus of Control: the degree to which an individual believes they have control or influence over the events in their lives. A person with a strong internal locus of control believes s/he has a great deal of control over their lives, while a person with a strong external locus of control sees things as happening to them as a result of external factors.

Monism: the theory that there is only one category of thing, or entity, while pluralism is the theory that there are many (H. Robinson, 2016).

Ontological Emergence: An entity that is both fundamental and dependent (see emergence, fundamental and ontological dependence).

Ontological dependence: An entity is dependent on other entities if the dependent entity would cease to exist if the entities which gave rise to it ceased to exist.

Order – chaos dynamic: The characteristics of a complex adaptive system exist as continuums ranging from complete order to complete chaos. The system will move dynamically along each of these continuums as the agents within the system adapt to other agents and their environment (including other complex adaptive systems).

Physicalism: A form of monism in which the physical is the one and only form of existence.

Pluralism: The theory that there are many categories of things

Reductionism: The belief that it is possible to understand everything by understanding the smallest elements and how those elements behave and interact.

Self-organization: The spontaneous appearance of system-level order arising out of (or emerging from) interactions among independent, yet interdependent agents. The order achieved tends to be dynamically stable, resisting eternal disturbances until a tipping point is reached.

Self-organized criticality: occurs when systems evolve to a point where 'avalanches' of virtually any size are possible. The frequency distribution of these avalanches follows an inverse power law, which results in fat-tailed behaviour.

Self-similarity is the property of an object being the same, or similar to, a part of itself. When viewing an object with self-similarity, zooming in or zooming out will present a similar view.

Sensitive dependence on initial conditions: a small change in the initial state of a system may be amplified over time, resulting in a large difference in later states of the system.

Supervenience: in a hierarchical system, upper-level properties are more than just the result of lower-level properties, they are inextricably linked – they supervene on the lower level. Any change in upper-level properties is the result of and, ultimately, can be explained by a change in elementary particles.

Tipping point: a point beyond which a system shifts radically into a different dynamic equilibrium state. The shift is potentially sudden and irreversible.

Curriculum Vitae

Candidate's full name:

Philip Andrew Lambert

Universities attended (with dates and degrees obtained):

MBA, University of New Brunswick, 1995

BESc, University of Western Ontario, 1984

Publications:

Lambert, P. A. (2018). The Complex Adaptive Process of Innovation Diffusion. *Manuscript Submitted for Publication*.

Lambert, P. A. (2018). The Order - Chaos Dynamic of Creativity. *Manuscript Submitted for Publication*.

Lambert, P. A. (2018). The Ontological Emergence of Creativity. *Manuscript Submitted for Publication*

Lambert, P. A. (2017). Understanding Creativity. In J. B. Cummings & M. L. Blatherwick (Eds.), *Creative Dimensions in Teaching and Learning in the 21st Century* (pp. 1–21). Rotterdam: Sense Publishers. https://link.springer.com/chapter/10.1007/978-94-6351-047-9_1

Conference Presentations:

Lambert P. A. (November 2017) *The Order – Chaos Dynamic of Creativity*, Creative Connections Conference, Fredericton, New Brunswick, Canada, November 16-18, 2017

Lambert P. A. (June 2014) *Innovations in Entrepreneurship Curriculum for Engineering and Science Students*, Deshpande Symposium for Innovation & Entrepreneurship in Higher Education, Lowell Massachusetts, USA, June 10-12, 2014