REVISITING THE DIALECTICAL RELATIONSHIP OF NATURE AND CULTURE IN CULTURAL-HISTORICAL PSYCHOLOGY: AN INTERDISCIPLINARY PERSPECTIVE

by

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BSc. (Honours)., McMaster University, 2009

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS

in

The Faculty of Graduate Studies

(Human Development, Learning, and Culture)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

December, 2011

Abstract

Vygotsky (1896-1934) was an eminent Soviet scholar who saw the fragmentation between Behaviourism, Gestalt Psychology, and Introspectionism as a "crisis in psychology," (Wertsch, 1985) and aimed to construct a research methodology that applied Marx's historical materialism to the psychological plane (Vygotsky, 1997c). To be able to both describe and explain the development of psychological processes unique to humans, the developmental history of the human species (phylogenesis), social practices and cultural tools and signs (sociocultural history), lifespan development (ontogenesis), and the development of psychological processes themselves (microgenesis) needed to be analyzed. Each developmental history, or genetic domain (Wertsch, 1985), has its own explanatory principle since the very mode of development changes. For phylogenesis, the explanatory principle is Darwin's theory of natural and sexual selection. For sociocultural history, it is the decontextualization of mediational means. For ontogenesis, it is the dialectical relationship between the natural and cultural lines of development. For microgenesis, it is the interfunctional relationships between psychological processes (Wertsch, 1985).

The purpose of this conceptual thesis was to apply the dialectical relationship Vygotsky explicated in ontogenesis—the dialectical relation between nature and culture—across the four genetic domains given current interdisciplinary research on the neurological underpinnings of development. The methodology of philosophical inquiry was used, consisting of an in-depth literature review, integration, and application. The conceptual thesis modified Vygotsky's genetic method of analysis in two primary ways. First, the research gathered showed that the dialectical relationship between nature and culture could be grounded by research based on technologies not available to Vygotsky and applied across all four genetic domains. Second,

there is a continuation of the natural and cultural lines from phylogenesis into sociocultural history given that the field of psychology no longer subscribes to the Critical Point Theory of the origin of culture (Geertz, 1973), which was popular during Vygotsky's time. The conceptual analysis is followed by an application using the mathematical development of the concept of abstract number as an example. A visual figure provides a research framework for future research on psychological processes, emphasizing the dialectical relationship between nature and culture across all four developmental histories.

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Acknowledgements

The first and foremost acknowledgement goes to my research supervisor, Dr. Jennifer Vadeboncoeur, who has been my encouragement and support even before the start of this thesis project. She saw the potential in my term paper and it was with her encouragement that I took up this thesis topic. She agreed to become my supervisor under very short notice at the beginning of her sabbatical leave. For this, I am eternally grateful. I have thoroughly enjoyed the shared space of intellectual conversation, and it is through her example of mentoring that I have truly come to understand Vygotsky's concepts of the general genetic law of cultural development and the zone of proximal development.

My sincere gratitude goes to my research committee members, Dr. Hillel Goelman and Dr. Jenna Shapka, who were also professors in previous courses. They will recognize the impact the discussions in their seminars and course projects have had on my research development through this conceptual thesis. Their inputs have been invaluable in culminating this project.

My warm regards to my parents who have relentlessly enforced the importance of education and have encouraged my scholastic journey. It is only with their support that I can freely engage in my academic pursuits.

My love to the close friendships and study buddies I have made here in Vancouver over a period of two short years. They have ensured I maintain a balance between work and play. A special mention goes to Milan Singh, who I have always turned to for academic counselling outside of the university, and Christine Klerian, who knows all the peaks and valleys I have had over the course of my Masters.

My acknowledgements also go to you, the readers, who make the effort of this conceptual thesis worthwhile.

To my academic predecessors

Chapter One: Introduction

Lev S. Vygotsky, a Russian psychologist, advanced a theory that was revolutionary for his time. Rather than emphasizing the role of biology over the environment, nature over nurture, or the reverse, nurture over nature, in his cultural-historical theory, he stated that human psychological processes develop as a result of contributions from both nature and culture. Vygotsky argued that both nature and culture should be studied in development, and also that psychology must be able to explain, rather than merely describe, the development of psychological processes. A methodology for moving from mere description to description and explanation in research was advanced by Vygotsky through a multi-level approach that requires analysis of the development of psychological processes in relation to other developmental histories, or so called genetic domains (Wertsch, 1985). More specifically, a fundamental feature of Vygotsky's theory is the requirement that the development of psychological processes (microgenesis), like attention and memory, be understood in relation to the developmental histories of the human species (phylogenesis), of social practices and cultural tools and signs (sociocultural history), and of the life course development of particular individuals (ontogenesis). Different explanatory principles that define the processes of development across each of these genetic domains reflect "*changes in the very mode of development*" and they draw from research across multiple disciplines (italics in original, Luria & Vygotsky, 1992, p. xii; see Appendix I for definitions of key concepts).

While Vygotsky constructed this unique and complex foundation for research, he has been critiqued for focusing his own research on the cultural contributions to development over and above the natural (Cole, 2007). Some have argued this was a result of his short academic career and the substantial challenges he faced given his ill health (Wertsch, 1985). Others have

argued that this resulted from a lack of access to data gathering technologies that have only become recently available (Wertsch & Tulviste, 1992). Indeed, though Vygotsky claimed a dialectical relationship between a natural and a cultural line in ontogenesis, he spent most of his time studying the impact of culture on development (Wertsch, 1985). In addition, he was less clear in articulating how nature and culture may influence the developmental histories across the other three genetic domains: microgenesis, sociocultural history, and phylogenesis. This thesis revisited Vygotsky's notion of the dialectical relationship between nature and culture across all four genetic domains, focusing on the neurological underpinnings of development.

The purpose of this conceptual thesis was to attend to the dialectical relationship between the natural and cultural lines that Vygotsky theorized for ontogenesis across the other three genetic domains in light of current research in several related disciplines, for example, anthropology, sociology and the neurosciences, with a focus on the developmental view from neurosciences. The method constructed was then applied to research conducted following Vygotsky's genetic method of analysis with a focus on the mathematical development of the concept of abstract number. Divided into four sections, this chapter begins by providing a brief overview of the historical context within which Vygotsky was working. The second section describes Vygotsky's genetic method as theorized. The third section states amendments to Vygotsky's theory as suggested by other researchers. The fourth section articulates research questions and relates them to a brief discussion of the methodology for this conceptual thesis. This section includes an introduction to the mathematical development of the concept of abstract number, and how it provides an application for the method constructed here. The final section is a summary of this chapter and an overview of the rest of the chapters in this conceptual thesis.

1.1 Historical Context for Vygotsky's Work

Vygotsky's research career peaked during 1924-1934 in a research milieu that was highly focused on the processes of naturalism and conforming to popular and changing interpretations of Marxism. In a speech in 1924, Vygotsky viewed the work of his contemporaries—the behaviourists, Pavlov and Watson, Gestalt psychologists, and introspectionists, lead by Wundt—as fragmented schools of psychology that relied upon disparate methodologies. He argued that without a unified goal, purpose, theory or methodology this constituted a "crisis in psychology" (Vygotsky, 1997c). One problem lay in the attempts of psychologists to define and rely on one explanatory principle for the development of all psychological processes (Wertsch, 1985). Vygotsky's response was to offer new theoretical concepts and processes, along with a new research method that incorporated different domains of development with different explanatory principles.

At the time, one goal of Soviet psychologists was to clarify and apply a popular version of Marxism, and features of Marx's philosophy are reflected in Vygotsky's works. According to Marx, socially organized forms of labour—and the social practices and cultural tools and signs that are invented in relation to the development of labour—are the key distinguishing factor of humans (Vygotsky, 1978). Engels elaborated on this theory and stated that culturally available tools influence the form of labour and change both nature and society. Speech, a sign system and also a cultural product, transforms human relations and behaviour. For Engels, Marx, and for Vygotsky, as humans developed the capacity to control nature and developed a repository of cultural tools and signs to do so, they not only created new forms of human society, but also created new forms of human consciousness. Marx argued that human nature is influenced by the qualitative and quantitative changes in society (Vygotsky, 1978). Implicit in Marx's method of

analysis was the dialectical unity of the individual in relation to the social system. Vygotsky saw as one of his main tasks the development of a Marxist psychology that was grounded in historical materialism (Wertsch, 1985).

Research in psychology at the time provided a description of some psychological phenomenon, as well as human behaviour, but not both a description and an explanation of both psychological processes and behaviours. Yet, all of these—description and explanation of both processes and behaviours—were necessary for an understanding of human consciousness. For example, the phenotype *describes* a physical inherited characteristic, whereas the genotype *explains* the inherited characteristic (Wertsch, 1985). Likewise, the experimental method describes the external manifestations of the human psychological processes under study, whereas a more in-depth study looking at the history and the source of the human psychological processes has the potential to provide explanations. Marx stated that "if the essence of objects coincided with the form of their outer manifestations, then every science would be superfluous" (Vygotsky, 1978, p. 63). The very purpose of science was to unravel the explanatory principles underlying the physical characteristics that were outwardly expressed. Vygotsky proposed the genetic method of analysis, wherein the history and the source of human psychological processes is taken into account, in order to provide an explanation and description. As Wertsch (1985) noted,

> Vygotsky's point is not that psychological research which fails to use a genetic method is invalid or useless. Elsewhere in his writings he explicitly stated that such research can make an important contribution to the overall picture of psychology. However, he believed that without genetic analysis one can only describe certain aspects of psychological processes and cannot understand internal workings and causal dynamics. (p. 18)

Through the genetic method of analysis, looking across the developmental histories and the development in the natural and cultural lines, psychology could both describe and explain the development of psychological processes.

1.2 Vygotsky's Genetic Method of Analysis

Vygotsky proposed that the development of any psychological process is the product of both nature and culture. Nature refers to biological and physiological development. According to Cole (1991), a definition of culture that is consistent with Vygotsky's perspective is found in the work of Kroeber and Kluckhohn (1952),

> Culture consists of patterns, explicit and implicit, of and for behaviour acquired and transmitted by symbols, constituting the distinctive achievements of human groups, including their embodiment in artefacts; the essential core of culture consists of traditional (i.e., historically derived and selected) ideas and especially their attached values; cultural systems may on the one hand be considered as products of action, on the other as conditioning elements of further action. (Kroeber & Kluckhohn, 1952, p. 181)

Cole (1991) highlighted that this definition of culture includes both material objects (cultural artefacts), as well as mental entities (values and ideas), which translates into the mediational means of tools and signs in Vygotsky's cultural-historical theory (see Appendix I for definitions of key concepts).

In his writing, Vygotsky separated a natural, or biological, line from a cultural line in ontogenetic development and noted that in different genetic domains, these lines have different emphases (Wertsch, 1985). Phylogenesis is the developmental history of the human species. Sociocultural history is the developmental history of a culture, along with the social practices and tools and signs of the culture, into which an individual is born. Ontogenesis is the developmental history of an individual over the course of life. Microgenesis is the developmental history of particular psychological processes (Wertsch, 1985). These developmental histories are not nested contexts. Instead, these four developmental histories are woven together, with interrelations between and across them. The natural line has a large influence in the domain of phylogenesis, and evolution precedes to a point when the cultural line becomes primary. The cultural line is emphasized in the domain of sociocultural history almost exclusively. It is only in

the domain of ontogenesis that Vygotsky stressed the dialectical relationship between the natural and cultural lines. Though, noted earlier, even here his work privileges the cultural line, perhaps, as a method for redressing the historical lack of research attention to the cultural line. Vygotsky was only beginning his medical studies when he died of tuberculosis in 1934 and did not have much time to discuss the domain of microgenesis in detail (although see Vygotsky, 1997a), but his student Alexander Luria extended this study and is lauded as the father of neuropsychology (see Luria, 1973).

According to Vygotsky, a central aspect of the crisis in psychology stemmed from the application of one explanatory principle across the development of psychological phenomena. Instead, he conceptualized the genetic method of analysis in which a separate explanatory principle for each of the four genetic domains is analyzed to describe and explain the developmental histories of psychological processes (Vygotsky, 1997b). It is important to note that the distinctions made between the natural and cultural lines, as well as the four genetic domains are purely for analytical reasons, and that development is not stratified into such neat categories. Vygotsky emphasized that each of the explanatory principles is not merely another type of explanatory principle, but rather that at each genetic domain there is a qualitative change in the very type of development, and hence the requirement for a new set of explanatory principles (Wertsch, 1985).

In the genetic domain of phylogenesis, the explanatory principle is Darwin's theory of natural selection. Organisms with certain characteristics better suited for the environment survived, while others perished. The organisms that survived to reproductive age were sexually selected and passed their genes to the next generation. In this method, the *Homo sapiens* species survived, while other hominid species became extinct. Vygotsky concluded the genetic domain

of phylogenesis was primarily determined by development in the natural line. He viewed the natural line as the foundation of elementary psychological processes. After a child develops speech and language, the cultural line takes over and leads to the development of higher mental processes. As cited by Lee (1985),

> If we compare the early development of speech and of intellect—which we have seen develop along separate lines in animals and in very young children—with the development of inner speech and of verbal thought, we must conclude that the later stage is not a simple continuation of the earlier. The nature of the development itself changes, from biological to sociohistorical. (Vygotsky, 1962, p. 51)

When culture emerged, Vygotsky envisioned, the explanatory principle of the decontextualization of mediational means in the genetic domain of sociocultural history would replace Darwin's theory of natural selection in phylogenesis as the mode of development.

In the genetic domain of sociocultural history, the explanatory principle of the decontextualization of mediational means enables individuals to become less reliant on the concrete experience of an object. Symbolic representations and linguistic signs ultimately enable humans to mentally develop representations that allow decontextualization. Vygotsky stated that humans are the only animals who are able to use external tools and psychological signs to mediate the behaviour of others and themselves. These means of mediation, or mediational means, include technical tools that are external, such as arrows that enable individuals to operate in the environment in specific ways. Human history also includes signs that are used to transform the individual's own behaviour. Signs can be either external or internal, such as tying a knot and using it as a memory aid or remembering an image as an aid for navigation. With the use of cultural tools and signs, humans are able to manipulate their environment beyond their perceptual field (Lee, 1985; Luria & Vygotsky, 1992). In the genetic domain of sociocultural history, Vygotsky emphasized development almost exclusively along the cultural line. It is this

explanatory principle that Vygotsky is most lauded for, so much so that his cultural-historical theory is also commonly known as the sociocultural approach (Wertsch, 1991).

Through internalization, individuals decontextualize mediational means in the genetic domain of ontogenesis. Internalization is a process that results in a cultural tool being utilized for the individual's own means and not simply as an imitation of previously observed behaviour. As the individual observes another utilizing a cultural tool, s/he begins to interact with the cultural tool and learns how to use the cultural tool (Vygotsky, 1978; Wertsch, 1985). It is this relationship between the child and the society that allows for development in the cultural line. Vygotsky (1978) termed social interactions that led to learning as the zone of proximal development, defined as the distance between the child's "actual development level as determined by independent problem solving" and the higher level of "potential development determined through problem solving under adult guidance or in collaboration with more capable peers" (p. 86).

Vygotsky advanced the explanatory principle of the dialectical relationship between the natural and cultural lines most completely in the genetic domain of ontogenesis. The biological development explained in the genetic domain of phylogenesis provides affordances for the child to utilise cultural tools and signs developed in the genetic domain of sociocultural history (Cole, 2007). Since the domain of ontogenesis is complicated to study, in particular because there are multiple explanatory principles at play, Vygotsky suggested researchers turn to the domain of phylogenesis where the natural line and the cultural line are not intermingled, to unravel some aspects of human behaviour. Even so, within ontogenesis Vygotsky assumed that the natural line develops in relative isolation until infancy, and then interacts with the cultural line through emergent interactionism (Wertsch, 1985). Vygotsky stated that the cultural line took over after

infancy, in the developmental history of human psychological processes, in particular through the internalization of speech.

Vygotsky was not clear in articulating his explanatory principle for the genetic domain of microgenesis. Microgenesis refers to the development of particular psychological processes. Wertsch (1985) stated that this includes short term changes and also long term changes, as individuals learn behaviours. Vygotsky emphasized interfunctional relationships between psychological processes, and suggested researchers refrain from isolating psychological processes; this unity may be a potential explanatory principle for microgenesis. With the advancement of brain imaging technology, to which Vygotsky did not have access, current researchers are able understand the brain development of humans (Wertsch & Tulviste, 1992). Infants have the most number of nerve cells, and as they grow, the neurons grow, and create connections developing a wiring network. The connections that are used are strengthened, while unused connections are removed. Specific cells respond to specific stimuli, resulting in the adult brain having highly specialized regions. The brain rewires itself according to experiences, and it is this neuroplasticity that allows the human species to be so adaptable to the environment into which the individual is born (Gopnik, Meltzoff, & Kuhl, 1999).

Each genetic domain has its own explanatory principle as the very type of development differs. Therefore, to conduct a genetic analysis, research from multiple disciplines is required. For example, in the domain of phylogenesis, the developmental history of the human species, research from the fields of anthropology, archaeology, and evolutionary biology is required. Likewise, in the domain of sociocultural history, the developmental history of social practices and cultural tools and signs, research looks to the fields of cultural anthropology, sociology, communication, and linguistics. For ontogenesis, the developmental history of a human within a

lifespan, and microgenesis, the developmental history of a particular psychological phenomenon, research in psychology, education, and neuroscience are predominant. With such multidisciplinary research, the likelihood of two forms of reductionism in research, that of biological reductionism (i.e., the assumption that the development of psychological processes is based solely on biological changes) and cultural reductionism (i.e., the assumption that the development of all psychological processes is based on the mastery of cultural tools and signs) are reduced (Wertsch, 1985). Therefore, Vygotsky's genetic method of analysis calls for interdisciplinary research.

1.3 Amendments to Vygotsky's Theory Given Current Research

During Vygotsky's time, research methodologies were limited by the technology available, in particular, brain imaging technology. The advancement in technology has led to a surge in knowledge, particularly that of the neurological underpinnings of development in human psychology. For example, with the advent of brain imaging technology, it is now possible to study the *in vivo* brain and observe how behaviour develops and/or changes the neuroanatomy. Likewise, there have been anthropological discoveries since Vygotsky's time that have led to new information and connections about the development of human psychological processes. Vygotsky conceptualized his theory and methodology on the basis of the research available to him in his society and time. These conceptualizations exist at each domain of the genetic method of analysis and can be supplemented by the current research available, with a focus on the neurological underpinnings of human development.

Vygotsky assumed that the natural line plays a dominant role in the genetic domain of phylogenesis. One of the key defining characteristics of *Homo sapiens* is the relative brain size to body size, with the development of the frontal lobes as a major contribution to the increased

brain size (Aiello & Dunbar, 1993; Reader & Laland, 2002). What may have caused the sudden expansion in brain size? The Hunting Hypothesis suggests that *Homo sapiens'* group hunting strategy allowed for large group sizes, and thus language and planning skills were required for social cohesion and group sustainability (Ardrey, 1970). This increased cognitive demand may have led to the expansion of the relative brain size, particularly of the frontal lobes, which are the seat of executive functions (Ardrey, 1970). Not arguing whether the expansion of the relative brain size led to the group hunting strategy, or vice versa, the development of the preliminary skills of planning and language highlights the key role of culture in the neurological underpinnings of development of *Homo sapiens* in the genetic domain of phylogenesis.

Vygotsky inferred that the natural line is primarily responsible for the development of elementary psychological processes, which precedes and provides allowances for the development in the cultural line. He is critiqued to have used research based on comparative studies between humans and other animals to emphasize the natural line in the domain of phylogenesis, but failed to focus on the development in the natural line of humans. Geertz (1973), an American anthropologist, pointed out that these comparative studies between humans and our closest living relatives, skews the timescale of phylogenesis in evolution. The connection in our phylogenetic tree was split in the Pliocene era when the hominids (*Homo* genus) and hominoids (primates) split. Instead, research needs to look to our hominid ancestors for research on the historical development of human psychological processes.

Vygotsky claimed that after biological evolution, as described by Darwin's natural selection, cultural evolution took over in the development of human psychological processes. This position, which reigned for half of the 20th century, is termed Critical Point Theory. As Geertz (1973) noted,

> Alfred Kroeber postulates that the development of the capacity for acquiring culture was a sudden, all-or-none, quantum-leap type of occurrence in the phylogeny of the primates. At some specific moment in the history of hominidization—i.e. the "humanization" of one branch of the primate line—a portentous, but in genetic or anatomical terms probably quite minor, organic alteration took place. (p. 22)

Critical Point Theory has three major considerations that Geertz systematically critiqued. The first consideration was the major gap in mental ability between humans and great apes. Geertz argued that the hominids (*Homo* genus) and hominoids (primates) split in the phylogenetic tree during the Pliocene era, after which significant evolution in the hominid branch led to the species *Homo sapiens*. The second consideration was that language, abstraction, symbolization was an all-or-nothing principle. Geertz suggested that the unit of measurement used in the timescale of cultural evolution is too large, and thus misses the gradual cultural evolution evident through stone tools. The third consideration is the psychic unity between various groups of human races. Geertz (1973) responded that no one gives serious consideration to the differences in the thought process of human groups. Therefore, Critical Point Theory, which was popular during Vygotsky's time, has been amended by anthropologists, and is no longer seen as a viable explanation for evolutionary processes. Elaboration of this argument provides evidence for the influence of the cultural line in phylogenesis long before Vygotsky argued it would have contributed to development.

It was thought that both the natural and cultural lines of development began at birth and it was also thought that the natural line of development within ontogenesis ended at infancy, after which the cultural line took over. With foetal monitoring technology and new methods for infant studies being conducted, there are many cases of culture having an influence on development in the prenatal environment, even before birth (Maurer & Maurer, 1988). With the help of brain imaging technology, and longitudinal and cross-sectional studies being conducted, there are

examples of the continuation of development in the natural line much later than infancy (Courchesne et al., 2000; Gogtay et al., 2004), thus potentially refuting the case that the development of the natural line ends at infancy in the genetic domain of ontogenesis.

The genetic domain of microgenesis has been overlooked, compared to the other three genetic domains, primarily because the technology Vygotsky had access to only allowed for post mortem studies (Luria, 1973). As brain imaging technology has become available, researchers who previously relied on post mortem analyses on brain slices could now study the brain *in vivo*, while the participant performs the behaviour under study. Brain imaging technology has also made it evident that the development in the domain of microgenesis relies both on the cultural line and the natural line as is demonstrated in the principle of neuroplasticity (Gopnik et al., 1999).

With amendments to cultural-history theory based on current research, there is evidence of the dialectical relationships between nature and culture across all four genetic domains. It is no longer thought to be unidirectional, wherein the cultural line builds upon the natural line, but rather that the cultural line can also influence the development in the natural line. The availability of new mediational means —such as recording machines, brain imaging technology, and archaeological discoveries, that were not available during Vygotsky's time—has changed the information and knowledge in the field of human development. With the supplementation of current research, this conceptual thesis revisited Vygotsky's genetic method reemphasizing the dialectical relationship between nature and culture across all developmental histories of the genetic method, with a specific focus on the neurological underpinnings of human psychological development.

1.4 Research Questions and Purpose

The overarching research questions driving this conceptual thesis are: 1) What does research on the neurological underpinnings of human development suggest regarding a dialectical relationship between nature and culture in each genetic domain—phylogenesis, sociocultural history, ontogenesis, and microgenesis?, and 2) How does the dialectical relationship between nature and culture manifest in each of the genetic domains given current research on the neurological underpinnings of human development? To answer these research questions, four sub questions were used: 1) What does research on the neurological underpinnings of human development suggest regarding a dialectical relationship between nature and culture in the genetic domain of phylogenesis?, 2) What does research on the neurological underpinnings of human development suggest regarding a dialectical relationship between nature and culture in the genetic domain of sociocultural history?, 3) What does research on the neurological underpinnings of human development suggest regarding a dialectical relationship between nature and culture in the genetic domain of ontogenesis?, and, 4) What does research on the neurological underpinnings of human development suggest regarding a dialectical relationship between nature and culture in the genetic domain of microgenesis? An application of this method was exemplified using the question: Recognizing these four genetic domains are interrelated, how might this the dialectical relationship be applied to research on the psychological processes of mathematical development of the concept of abstract number?

The purpose of this conceptual thesis was to revisit Vygotsky's genetic method of analysis given research on the neurological underpinnings of human psychological development. The assumption that nature plays a singular role in the domain of phylogenesis up until a critical point, after which culture takes over was amended in lieu of current research. The assumption

that culture plays a dominant role in the domain of sociocultural history was amended in lieu of current research. Instead, the dialectical approach that Vygotsky explicated only in the domain of ontogenesis was applied across all the domains of the genetic method, emphasizing the influence of both nature and culture in the developmental histories of human psychological processes with a focus on the neurological underpinnings of human psychological development. In ontogenesis, the notion that development occurs in the natural line until the child masters language, after which development primarily occurs in the cultural line was revisited given current research. Brain imaging technology has allowed for research on the mechanisms driving the development of psychological processes, and consolidated the genetic domain of microgenesis. In addition, an application of the genetic method of analysis incorporated the suggested dialectal relationship across all the domains. In particular, the psychological processes of mathematical development of the concept of abstract number was analysed through the genetic method.

The methodology employed in this conceptual thesis was philosophical inquiry. Identifying the philosophical orientation driving the research was helpful in making the researcher aware of the foundations and assumptions it entailed. A literature review, with translations of Vygotsky's work and anchor texts as per the guidance given from supervisors and key members of included disciplines, was conducted. A reference list for each genetic domain was gathered, supplemented with current research. In this manner, the research questions were explored, serving the purpose of this conceptual thesis.

1.5 Summary

During Vygotsky's prime the research milieu focused on naturalism and conforming to current popular versions of Marx's ideas. Vygotsky saw a crisis in psychology resulting from a lack of theory and methodology that incorporated the various psychological perspectives into one

unified discipline of psychology capable of both describing and explaining the development of human behaviour and psychological processes (Wertsch, 1985). Vygotsky proposed a genetic method in which the developmental history of human psychological processes is analysed over the four domains of phylogenesis, sociocultural history, ontogenesis and microgenesis. Although Vygotsky implied that nature and culture are interrelated over the course of development, this dialectical approach was only stressed in the domain of ontogenesis (Wertsch, 1985).

The purpose of this conceptual thesis was to apply the dialectical approach that Vygotsky implied only in the domain of ontogenesis, across all the domains of the genetic method, emphasizing the influence of both nature and culture in the developmental history of human psychological processes, with a focus on the neurological underpinnings of human development. An application of this research methodology on the psychological processes of mathematical development of the concept of abstract number provides an example of research conducted in the genetic method of analysis. The methodology employed for this conceptual thesis was philosophical inquiry, through an in depth literature review, synthesis, and application.

This chapter provided a brief overview of Vygotsky's genetic method and the research questions driving this conceptual thesis. Chapter 2 consists of the literature review expanding on the concepts explored in this thesis. Chapter 3 expounds on the methodology used for this conceptual analysis. Chapter 4 delves into the conceptual analysis and addresses the research questions. Chapter 5 provides the implications of Vygotsky's genetic method of analysis to research using visual representations of figures, and an example of the application of the research methodology on the mathematical development of the concept of abstract number. Chapter 6 is the last chapter, summarizing this conceptual thesis, stating the limitations inherent in this thesis, and the future directions in research.

Chapter Two: Literature Review

The purpose of this conceptual thesis was to revisit Vygotsky's cultural-historical theory given the research that has been conducted since his time with a focus on the neurological underpinnings of human development. In essence, the dialectical relationship between the natural line and the cultural line that Vygotsky applied to the domain of ontogenesis is applied across all the genetic domains of development. This chapter reviews that literature in relation to Vygotsky's cultural-historical theory: during his time, since his time and the current time. The sections in this chapter are derived from the research questions driving this conceptual thesis: 1) What does research on the neurological underpinnings of human development suggest regarding a dialectical relationship between nature and culture in each genetic domain—phylogenesis, sociocultural history, ontogenesis, and microgenesis? 2) How does the dialectical relationship between nature and culture manifest in each of the genetic domains given current research on the neurological underpinnings of human development?, and; 3) Recognizing these four genetic domains are inter-elated, how might this amended theory be applied to research on particular psychological processes such as the mathematical development of the concept of abstract number?

This literature review has five sections. The first section explores the influence of Marxism on Vygotsky's cultural-historical theory. Following this, the second section explores in detail cultural-historical theory, particularly the explanatory principle identified for each genetic domain. The third section analyzes Critical Point Theory in evolution, which was popular during Vygotsky's time, and the amendments to his theory as a result of Geertz's critique of Critical Point Theory (Wertsch, 1985). The fourth section looks at new technologies as new mediational means and the potential amendments to Vygotsky's theory that surface as a result of the data

currently available. The fifth section expands on the reason behind choosing mathematical development of the concept of abstract number as an example of research conducted in the genetic method of analysis. This chapter ends with a summary of the literature review.

2.1 Influence of Marx in Vygotsky's Work

Marx stated that human consciousness is a result of practical activity of the individual and the interaction with the environment (Lee, 1985). Consequently, researchers themselves are influenced by the social milieu that is characterized in part by the topics of research deemed appropriate and suited for study in particular social fields. Therefore, the influence of the sociocultural history of Vygotsky on his cultural-historical theory must be analysed, in order to adhere to Marx and Vygotsky's holistic or genetic method of analysis. During Vygotsky's time, naturalism had a strong hold on the field of research, and the drive of Soviet schools of psychology was to clarify and implement Marxism in their theories. As Vygotsky (1978) stated,

> I want to find out how science has to be built, to approach the study of the mind having learned the whole of Marx's method...In order to create a theory-method in the generally accepted scientific manner, it is necessary to discover the essence of the given area of phenomena, the laws according to which they change, their qualitative and quantitative characteristics, their causes. (p. 8)

Lee (1985) analyzed the intellectual origins of Vygotsky's work in order to clarify the ways in which Marx's ideas influenced his ideas. He identified four areas of influence in addition to a general similarity: Marx and Vygotsky both aimed to explain individual human consciousness in relation to society.

First, Marx and Vygotsky both claimed that consciousness was the result of a uniquely human principle of development given the natural activity of animals and the social activity of humans. Thus, the factor that differentiated humans from other animals is organized social labour (Lee, 1985). Darwin's theory of natural and sexual selection was sufficient in explaining

the natural activity of animals, however, the study of the social activity of humans called for a new analysis introducing the principles of historical materialism (Lee, 1985). This was the intellectual origin of Vygotsky's natural and cultural lines of development.

Vygotsky viewed human psychological processes as having three levels of development: elementary, rudimentary and higher psychological processing, which translates into reflexes, conditioned responses and intelligence (Luria & Vygotsky, 1992). The elementary level of psychological processes is shared by humans and other animals, and consists of reactions to nature that are determined by biological constraints and allowances such as automatic reflexes. These instincts are not learned, imitated or a result of trial and error. The natural line is the foundation for elementary processes and provides affordances and constraints for the cultural line to develop within (Wertsch, 1985). The rudimentary level of psychological processing is the developmental precursor to the higher level of psychological processes and is likened to conditioned responses, where an instinctive reflex is learned to respond to unconnected stimuli. Vygotsky noted that only vertebrates developed the second stage of psychological development (Luria & Vygotsky, 1992). Vygotsky termed the third level of psychological development of higher psychological processes as intelligence, which is only found in human psychological processing. Intelligence is the combination of conditioned responses resulting in new behaviours, including new psychological processes, with their own biological functions (Luria & Vygotsky, 1992). Vygotsky advanced Marx's theory through his concept of semiotic mediation. He argued that as the child was able to internalize language, development moved from elementary psychological processes to higher psychological processes.

Second, Marx's theory states that it is through the practical activity of the individual and the interaction with the environment that humans create their own reality and develop

consciousness (Lee, 1985). Vygotsky transformed this concept from the social plane into the psychological plane. Vygotsky's rejected empirical reductionism and opted to follow Marx's definition of human consciousness. He viewed consciousness as neither behaviour, nor separate from it, but rather a factor in the organization of practical activity (Lee, 1985). Expanding on Lee's correlation between Marx and Vygotsky, Vygotsky conceptualized culturally mediated tools and signs. Tools are objects in nature that humans manipulate to master their environment (Wertsch, 1985). For example, bows and arrows allowed humans to hunt from a distance, allowing the arrow to travel at speeds faster than humanly possible, and pierce and disable the prey, in a manner that would not be possible with human physiology. Signs are objects in the environment that humans use to represent and control the behaviour of others and their own behaviour, both externally, and once internalized, internally (Wertsch, 1985). Vygotsky used the example of a tying a knot on the finger as a memory aid. The knot itself does not have any meaning or purpose, but rather the meaning of what the knot represents, allows humans to control their own behaviour (remember) through external or internal means. According to Vygotsky, it was the shift of using external culturally mediated signs to master one's own memory that led to cultural development from the societies between the prehistoric and pre-industrial periods to the current day society (Luria & Vygotsky, 1992). It is through the interaction with culturally mediated tools and signs that higher psychological processes develop.

Third, according to Marx, the activity of the individual is based on the organization of production and consumption in a society (Lee, 1985). For example, in North America, we are no longer producing or consuming arrows to bring food to the table, rather we now produce and consume food bought from the grocery store. Therefore, the need for arrow makers has been replaced by the need for cashiers. In essence, the consumption of an individual leads to the

production of products available for consumers, following the simple functionalism of supply and demand. This dialectical relationship between production and consumption creates a dialectical relationship between the social organization and individual consciousness. The relationship between production and consumption, along with the social relations that result from the economic structure underlying this relationship, mutually constitutes social practices—or routines of behaviour coupled with speech—and cultural tools, signs, and processes that mediate human experience and ultimately lay the groundwork for consciousness (Lee, 1985).

Vygotsky used this relationship from the social plane and applied it to the psychological plane, stating that all psychological processes are functionally related and presuppose one another (Lee, 1985). Learning, for instance, presupposes perception and attention, which are functionally required for learning. Therefore, this dialectical relationship on the psychological plane demands that research not separate psychological processes, but must rather take a holistic perspective investigating the functional connections between psychological processes (Lee, 1985). Lee connected Vygotsky's theses about the interfunctionality of psychological processes, to Marx's dialectical relationship between production and consumption with human consciousness.

Fourth, Marx reasoned that since individual consciousness is based on the production and consumption of the society, the consciousness of the individual changes with the time and place. Therefore, consciousness needs to be studied historically and genetically (Lee, 1985). Rather than viewing development as an accumulation of cognitive changes, Vygotsky viewed development as the revolutionary interfunctional reorganization of consciousness as the child interacted with the society, and more specifically culturally mediated tools (Lee, 1985). With this

overview of Marx's influence on Vygotsky's work, the next section explores in detail the concepts of Vygotsky's cultural-historical theory.

2.2 Vygotsky's Explanatory Principles for Each Genetic Domain

In the research milieu of Vygotsky, Behaviourism (Watson), Gestalt Psychology (Lewin), and Introspectionism (Wundt) were key theories of the time in Soviet psychology. Vygotsky labelled the fragmentation in the disciplines of psychology as the "crisis in psychology." Part of the crisis was that these schools of psychology were attempting to apply one explanatory principle to explain all of development. Instead, Vygotsky argued for the need to decipher human development in relation to multiple developmental histories and to identify an explanatory principle for each (Wertsch, 1985). The four developmental histories and their explanatory principles are elaborated next given the key concepts that have been defined in Appendix I.

In phylogenesis, the developmental history of the human species, Vygotsky applied the explanatory principle of Darwin's theory of natural and sexual selection (Wertsch, 1985). Natural and sexual selection described and explained the process of evolution that led to the emergence of *Homo sapiens.* During Vygotsky's time, evolution was considered to occur to a point when a small, albeit significant anatomical evolutionary change allowed for the sudden rise of culture. This "critical point" enabled the rise of culture, after which humans were able to develop culturally mediated tools to master nature (Wertsch, 1985).

After natural selection had followed its course, cultural change took over in the evolution of humans. Vygotsky termed the developmental history of cultural change as the genetic domain of sociocultural history. For sociocultural history, the explanatory principle was the decontextualization of mediational means (Wertsch, 1985). Objects in nature can become mediational means if and when the object serves to allow humans to master either their

environment or themselves. Decontextualization of mediational means is the ability of humans to use symbolization, abstraction and language outside of the concrete environment, and immediate physical environment (Wertsch, 1985). Vygotsky noted that the language of the early humans was solely rooted in reality and did not allow for abstraction. Likewise, Donald (1993) postulated three stages of the origin of culture and cognition and noted that in preliterate oral cultures all experiences were stored as memory. As the culture developed, new retrieval properties were required to lessen the load on the biological working memory, and so symbolic representation evolved (Donald, 1993). A study between literate and illiterate participants from the same culture of Uzbeks found that illiterate people were not able to solve problems outside of their own physical experience, and said "We always speak about things we see. We never speak about the things we did not see" (Kotik-Friedgut, 2006, p. 45). Therefore, the plasticity of early humans was limited by the ways that their language functioned, for example, to imprint experiences in memory and to reproduce stimuli.

The decontextualization of mediational means and the mental abilities gained through the function of language to categorize and abstract objects from a context are the key modes of development in the cultural line for contemporary societies, according to Luria and Vygotsky (1992). For example, humans are able to think about and imagine a situation within which they are not presently interacting. This ability allows humans to remember the past, and create the future, while remaining in the present. Decontextualization of mediational means allows for mathematical computations in the mind, understanding what is being read without actually experiencing it in reality, manipulating sign systems, computer coding, music notation, and is the explanatory principle of the development of culture and society. Appendix II contains a list of significant cultural tools that have shaped the sociocultural history of the current society.

Vygotsky called the developmental history of the individual, ontogenesis, and explicated a dialectical relationship between the natural and cultural line. An individual develops through the development in the natural line, and the sharing of culturally mediated practices, tools and signs from one generation to the next (Cole, 2007). In his work at the Institute of Defectology, Vygotsky realised that a disruption in the natural line—for example, deafness—potentially disrupted development in the cultural line. While he theorized that development along the natural line had to proceed to certain point for cultural development to follow, he emphasized that auxiliary signs could be used to enable cultural development for children with many disabilities. This notion of compensation was a key factor in Vygotsky's success with children with disabilities, along with his attention to the cultural stigma often attached to disabilities. In fact, he argued that, frequently, the cultural construction of the meaning of a disability was often a more problematic factor in development, than the disability itself (Vygotsky, 1993). The key marker of development shifting from biological development to cultural development was the development of speech language in children. For children who were hard of hearing or deaf, sign language could be used to foster development along the cultural line. He postulated that this shift in emphasis occurred at approximately 18 months of age (Wertsch, 1985). Given research on the development of language since his time the age range within which language develops has been found to begin much earlier and have a larger variation (Kuhl & Rivera-Gaxiola, 2008). Vygotsky did not explicitly identify an explanatory principle for the genetic domain of ontogenesis, and Wertsch (1985) stopped short of stating the dialectical relationship between the natural and cultural lines as the explanatory principle for ontogenesis.

The genetic domain of microgenesis is the developmental history of particular psychological processes. Again, Vygotsky did not explicitly state an explanatory principle for the

genetic domain of microgenesis, however he emphasized interfunctional relationships between psychological processes. As Luria (1973), Vygotsky's student and colleague and the father of neuropsychology, stated,

> The fact that they [psychological phenomena] were all formed in the course of long historical development, that they are social in their origin and complex and hierarchical in their structure, and that they are all based on a complex system of methods and means, as the work of the eminent Soviet psychologist Vygotsky (1956; 1960) and his pupils (Elkonin, 1960; Galperin, 1959; Leontiev, 1959; Zaphrozhets, 1960;) has shown, implies that the fundamental forms of conscious activity must be considered as complex functional systems; consequently, the basic approach to their 'localization' in the cerebral lobes must be radically altered. (p. 29-30)

Psychological processes do not develop in isolation or sequentially, but rather co-develop with one another. For example, the psychological process of memory develops with attention and perception (Lee, 1985). Hence, Vygotsky emphasized studying the interfunctional relationships of psychological processes.

In summary, Vygotsky proposed four developmental histories also called genetic domains and a unique explanatory principle for two of these domains. For the genetic domain of phylogenesis, the explanatory principle he identified was Darwin's natural and sexual selection. For sociocultural history, the explanatory principle Vygotsky stated was the decontextualization of mediational means (Wertsch, 1985). For the genetic domains of ontogenesis and microgenesis, Vygotsky did not explicitly state the explanatory principle, however, it is plausible that the dialectical relationship between the natural and cultural lines, and interfunctional relationships, may be potential explanatory principles for ontogenesis and microgenesis respectively (Wertsch, 1985), granted they are supported by research.

2.3 Geertz's Critique of the Critical Point Theory of the Origin of Culture

Vygotsky's theories were based on the information and knowledge available at his time. One theory that was popular during his time, the Critical Point Theory, was the cited solution for the origin of culture. The basis of the theory was that natural evolution followed its course until one small, albeit significant evolutionary phenomena enabled humans to communicate through language. This significant event allowed for cultural development of culturally mediated tools, which were shared from one generation to the next (Geertz, 1973).

Geertz, an American anthropologist, postulated that humans are hierarchically stratified much like Vygotsky's hierarchy of psychological processes, in that there are various facets of human development such as organic, psychological, social and cultural levels. Geertz (1973) recommended that interdisciplinary research from different fields is required to understand human development. He defined culture as, "a historically transmitted pattern of meanings embodied in symbols, a system of inherited conceptions expressed in symbolic forms by means of which men communicate, perpetuate, and develop their knowledge about and attitudes toward life" (p. 89). Geertz (1973) followed the theory that humans use external objects to control their own behaviour, much like Vygotsky's theory of the mediation of cultural tools, allowing for the development of higher psychological processes. However, he did not hold a sequential view of cultural development following biological evolution, but rather theorized the two as overlapping mechanisms. The Critical Point Theory was based primarily on three assumptions: 1) that there is a large gap in mental ability between humans and other animals; 2) that symbolization is an all-or-nothing phenomenon and; 3) that psychic unity exists amongst all humans. Geertz's critiques to these three points are explored next.

First, Geertz (1973) noted that Critical Point Theory was based on studies finding a large gap in the mental ability between humans and other animals. These animal studies often compared the mental capabilities of primates to that of humans, based on the fact that they are the closest living ancestors to humans. Geertz noted that the evolution since the hominoids (primates) and the hominids (*Homo* genus) split in the Pliocene era (~5.3 million years ago). Since then, the hominid genus has evolved and many species such as *Homo habilis, Homo erectus, Homo neaderthalensis*, Australopithecines have emerged and become extinct. Geertz (1973) argued that the mental capability of *Homo sapiens* must be compared to the closest relative ancestor, and not simply to the closest relative living ancestor. A problem in turning to *Homo sapiens'* ancestors to study the historical development of human psychological processes, is that researchers have to assume ancestral culture and behaviours by analysing the cultural artefacts that have survived natural forces. For example, researchers are not able to observe the use of cultural tools, but are left to infer that a carved out stone that has survived erosion and is recovered in fossil records, was presumably used as a bowl. Nevertheless, directly comparing the mental capability of humans to other animals' is not valid, since much of evolution has occurred since that the split between *Homo sapiens* and other animals of the current day.

Geertz's critique is also a critique of Vygotsky's work, which relied on experiments by Kohler on chimpanzees that were lauded as finding the missing psychological link between animals and humans (Luria & Vygotsky, 1992). In these experiments, chimpanzees were required to problem solve, remove obstacles and use tools. What Kohler found was that chimpanzees were able to use sticks as multi-purpose tools, only if the stick and the objective of getting the fruit were in the same visual field of the chimpanzee. Once a chimpanzee used a stick as a tool, other chimpanzees immediately imitated the tool use. Vygotsky noted that since little is

known of our relative ancestors research in phylogenesis needs to turn to chimpanzees that have the closest physiology and brain mechanisms as humans (Luria & Vygotsky, 1992). From Kohler's experiments, Vygotsky noted than the differentiating factor of humans from other animals is the decontextualization of mediational means. The imagination of man, the ability for the decontextualization of mediational means, allowed humans to use tools and master nature beyond the immediate physical properties of the environment (Vygotsky, 1997a).

The second critique of the Critical Point Theory is that the ability to use symbolization, abstraction and language is an all-or-nothing ability, for example, either an organism can communicate using language or not. Following Geertz (1973), the timescale unit of measurement is too large to capture the stages of cultural development. He pointed to the gradual evolution of stone tools, which occurred rapidly relative to biological evolutionary stages. Evolutionary paths of species are observed over eras consisting of millions of years, however, the development of stone tools occurred within thousands of years. Therefore a more sensitive timescale unit is required to capture the evolution of stone tools, and the development of culture in hominids (Geertz, 1973).

Archaeologists studying the cultural artefacts of human ancestors have categorized the tools according to the type of tools, the species associated with the tools, and the time of the tools (Richerson & Boyd, 2005). The earliest tools are the Oldowan tools, which are simply pebbles that were struck to remove flakes from one face of the pebble, creating a sharp tip. Oldowan tools were made 2.6 million years ago, and were primarily used by *Homo habilis*, who then passed it on to *Homo erectus*. *Homo erectus* further evolved the Oldowan tools into Acheulean tools 1.7 million years ago, and is characterized by bifacial tools. They were replaced by Mousterian tools, which were primarily used by Australopithecines 30, 000 years ago, and are

characterized by thin and sharp flakes. This culturally mediated tool predates the emergence of *Homo sapiens*, which conflicts with Critical Point Theory. With *Homo sapiens*, the Microlithic tools were developed 8,000 years ago, which are geometric pointed tools that are attached to sheaths to make arrows and spears. This further evolved into Neolithic tools, consisting of polished tools resulting in tools such as axes (Richerson & Boyd, 2005). The evolution of stone tools, and the evidence of tools that predate the emergence of *Homo sapiens*, support the theory of cultural development being a gradual process, rather than a characteristic emerging at a single critical point in the evolution of *Homo sapiens*. Vygotsky did refer to the evolution of culture, particularly when comparing the societies between prehistoric and pre-industrial times to the current society (Luria & Vygotsky, 1992). However, these comparisons are within *Homo sapiens*, by which development in the cultural line had already evolved to a great extent.

The third point of Critical Point Theory is based on the assumption that there is psychic unity among all humans. Geertz (1973) pointed out that no serious study is given to the differences in thought process between human groups. He proposed that culture is not simply a garb over a uniform human nature, but rather that culture is the very foundation of a human being. His rationale was that studies that sought to find universals between human groups, upon deeper analysis, often resulted in finding differences in human groups. He stated that culture is the controlling mechanism for behaviour (Geertz, 1973), similar to Vygotsky's view of the development of higher psychological processes through interaction with cultural mediational means.

Wertsch (1985) suggested that Geertz's critique of Critical Point Theory should be a theoretical amendment to Vygotsky's cultural-historical theory. The evidence gathered by Geertz, four decades after Vygotsky's death, showed that biological evolution does not suddenly

transfer to cultural development at a critical point. While Vygotsky assumed that the genetic domain of phylogenesis was predominantly development in the natural line—until the emergence of *Homo sapiens* when cultural development took over—Geertz's critique showed that cultural development was a gradual process, predating the emergence of *Homo sapiens,* and overlapping with the natural evolution of hominids. Indeed, Geertz's (1973) work provides an example of the ways Vygotsky's work may be amended in relation to more recent research. In addition, as the next section highlights, Vygotsky's theory may need amendments in light of research enabled by the development of new mediational means or, more specifically, new technologies.

2.4 New Mediational Means: Advancements in Technology

Since the 1930's, when Vygotsky last wrote, new technologies have drastically changed the research field of human development and created the field of neuroscience. This development of technology is in keeping with Vygotsky's cultural-historical theory: the advancement of technology is the modification and evolution of culturally mediated tools, or mediational means, which in turn influences the development of human consciousness. Vygotsky (1997c) stated that science sees through the eyes of technology, and that it was imperative that psychology develop its own thermometer so that a research method that serves psychology could be developed. In this section, several new technologies are discussed with the potential to inform amendments to Vygotsky's cultural-historical theory.

Vygotsky, and his student Luria, are known to be the founders of neuropsychology. Vygotsky's work in the Institute of Defectology allowed for comparative behavioural studies with participants who had a certain disruption in their development and participants who did not (Wertsch, 1985). Animal studies were another form of comparative studies that were popular

during Vygotsky's time. Initially, human brain studies could only be conducted post mortem, through comparative studies: after a patient died, the brain anatomy was compared to that of a healthy brain and the subsequent conclusion was inferred. As brain imaging technology became available, researchers who previously relied on post mortem analyses of brain slices began to study the brain *in vivo*, while the participants performed particular behaviours. From electrodes that detect the electric activity when a nerve cell is activated, to sophisticated fMRI studies, neuroscience has given psychology the biological link to behaviours and psychological processes (Gopnik et al., 1999).

With the development of audio and video recording devices, it was possible for researchers to capture the participants' actions and behaviours, and replay it as many times as required for accurate coding and analysis (Gopnik et al., 1999). Recording technology allowed for researchers to conduct double blind studies, in which the researchers were unaware of the experimental group of the participant and could take observational notes, theoretically, without a bias. It also allowed for verification of observations from several researchers. Therefore, recording technology allowed researchers to follow the rigors of the scientific method, in which only observable data is collected and the validity and reliability of the study tested.

With the advent of computers, it was possible to isolate the human participant from the external environment and present the stimuli on a monitor, allowing for a virtual reality. Recordings of a participant's reaction time and accuracy in responding, or tracking their eye movements while they scanned stimuli could also be analyzed (Gopnik et al., 1999). Computers allowed for large sets of data and statistics to be computed within minutes, instead of a researcher processing the same mundane formula for each data set. Data computation became much more efficient and human error was mitigated.

Foetal monitoring technology has allowed doctors and researchers a window into the development in the prenatal environment. Ultrasounds provide images and movement of the foetus in the womb. The technology is still evolving from grainy images to three dimensional, high definition images (Woo, 2011).

Single cell studies where a metal electrode is inserted in the brain were conducted on animals. This type of technology allowed for extremely localized readings of the electrical activity within a single neuron, or multiple electrodes in multiple neurons. Although this technology provided extremely high temporal and spatial resolution, it's highly invasive methodology allowed for animal studies only, although even with animal studies ethical issues are often raised (Damon & Lerner, 2008).

With more sophisticated technology, came Electroencephalography (EEG) and later Magnetic Electroencephalography (MEG), in which the electrical activity or the resulting magnetic field of the brain is detected from the scalp. This methodology has high temporal resolution and is also used in Event Related Potentials (ERP) where the electrical activity is correlated with behaviour, and indicates electrical spikes of activity when the participants perform a certain task. The temporal resolution of EEG and MEG allows researchers to capture brain activity even before the participant is able to respond. However, since the electrical activity is measured from the scalp, the spatial resolution of EEG and MEG are poor and can only indicate the general location of brain activity (Damon & Lerner, 2008; Kuhl & Rivera-Gaxiola, 2008). The counter-mechanism of an EEG is Transcranial Magnetic Stimulation (TMS), in which a magnetic wand over the scalp induces electrical activity in that area, and the resulting behaviour or action of the participant is recorded.

Computer tomography (CT scans) is a series of x-rays of the brain. Analysis of the absorption of x-ray beams indicates the brain volume and mass. CT scans allowed researchers to look inside brain structures, but the procedure has poor spatial and temporal resolution (Damon & Lerner, 2008).

In Positron Emission Tomography (PET scans), radioisotopes in the form of labelled metabolically active chemicals are injected into the participant, and when these isotopes react through cell metabolism, they emit gamma rays that are detected by sensors and translated into an image allowing for the localization of the brain activity. This invasive and expensive procedure allows researchers to study the internal brain activity and cell metabolism (Damon & Lerner, 2008).

Magnetic Radio Imaging (MRI) emits a magnetic field and as the neurons align to the magnetic field, the sensors detect the motion and translate them into two and three dimensional images of the brain. MRI's have a high spatial resolution. An extension of the MRI is the Functional MRI (fMRI), in which the magnetic activity of deoxygenized haemoglobin and oxygenized haemoglobin is detected. However, this is an indirect measure of brain activity, wherein the metabolic activity of oxygen uptake of cells indicates the brain activity, and hence has delayed temporal resolution (Damon & Lerner, 2008; Kuhl & Rivera-Gaxiola, 2008).

Advances in brain imaging technology allow for *in vivo* studies, however, there are still limitations of technology that hold back the potential for research in child development. For example, brain imaging techniques require the participant to be immobile in noisy machines that have small spaces, which as any child care provider knows is a constraint for studying infants' brains (Kuhl & Rivera-Gaxiola, 2008). With the advancement of brain imaging technology,

scientists are better able to understand the brain development of humans though the technologies are still, themselves, evolving (Gopnik et al., 1999).

The examples of advancements in brain imaging technology that were not available during Vygotsky's time have allowed researchers to gather new types of data. This is consistent with Vygotsky's theory: as human culture builds over time, new technologies as mediational means, enable researchers to do more sophisticated analyses. It is through the mediational means of brain imaging technology that researchers are now able to look into the *in vivo* brain and study behavioural neuroscience. This new field of study may enable the conditions for the development of an explanatory principle for the genetic domain of microgenesis.

2.5 Example of Applying Genetic Method of Analysis

Mathematical development of the concept of abstract number is an interesting psychological process that allows for an example of the use and application of Vygotsky's genetic method of analysis. Mathematics is a culturally developed sign system that shapes behaviour, through computational tasks like long division, while at the same time enabling internal mental processes, like cognitive computations that do not require pencil and paper. One aspect of mathematics is the abstract concept of number, an understanding of which typically begins in formal schooling. The concept of abstract number requires having a mental representation that each Arabic numeral represents a defined quantity. The decontextualization of mediational means of abstract number requires the individual to conceive that the numerical properties are independent of the physical properties (Soltesz, Szucs & Szucs, 2010). For example, when comparing three grapes to one watermelon, the number of grapes is larger, but the watermelon looks larger. Also, the grapes in their own entity do not have any "threeness" to them, it is only when they are counted as a collective set that they construct the characteristic of

being three grapes. Studies suggest that there is a conceptual shift in children when they gain an understanding of the concept of abstract number (e.g., Cantlon, Libertus, Pinel, Dehaene, Brannon, & Pelphrey, 2009). This conceptual shift in the psychological processes used is an example to demonstrate research methodology conducted under the genetic method of analysis. In order to prepare for the application of the genetic method to the development of the abstract concept of number, three more Vygotskian concepts need to be defined here for use later: the general genetic law of cultural development, the zone of proximal development, and the development of concepts.

The general genetic law of cultural development states that any function of development appears twice, on two planes. First it appears in the social, inter-psychological plane, where the child observes the function, and over interaction with the function internalizes it to the second intra-psychological plane (Wertsch, 1991). It is through the interaction in the social plane that the child learns how to approach problems, situations, and learns planning and problem solving. During this interaction, the mind moves beyond the confines of the body and is in a shared space between the child and the adult. For example, when a child is trying to remember a fact, a parent may guide the child through leading questions. In this scenario, who is the one remembering the fact? It is this collective thinking of the parent and the child that Vygotsky stated as the law of development (Wertsch, 1991). In the case of the abstract concept of number, the child learns counting and numbers in a formal manner under the tutelage of a teacher, and once the child grasps the concepts of abstract number, s/he is then able to use it for his or her own purposes, such as dividing candy amongst friends, outside of the formal setting.

Vygotsky's (1978) zone of proximal development, as noted by Wertsch (1985), is a particular instance of the general genetic law of cultural development. It is the interaction

between the child and the adult, while they are in the shared space interacting with the cultural tool. It is the zone between what the child can do independently and what the child can do with the aid of an adult or more capable peer (Wertsch, 1985). In mathematics, and the development of the concept of abstract number, as the child learns counting and numbers, they are challenged to answer questions that are just above their actual level of development.

According to Vygotsky (1997b), children develop rich, emotive, experiential concepts in their day to day living. He stated three levels of experiences; 1) historical experiences, 2) social experiences, and, 3) doubled experiences. Historical experiences are the innate inborn responses as a result of development in the natural line. Social experiences are those the child experiences by observing others. Doubled experiences are when the experience is first imagined, and then consequently the behaviour follows, and, thus, it is experienced twice (Vygotsky, 1997b). These everyday concepts form the foundation for scientific concepts, which are defined as abstract, systematic, and linked through linguistic representations, rather than lived experiences. Rather than replacing everyday concepts, scientific concepts rely on everyday concepts in particular with respect to the system of judgments that enables representations of concepts to relate to one another. Development moves from heaps (grouping unrelated objects together), to complexes (coherent understanding of words and symbol meaning), to pseudoconcepts (concepts with experiential reasoning rather than logical or abstract reasoning), to concepts (logical or abstract reasoning) (Berger, 2005). In the case of mathematics, the concept of abstract number does not lie inherently in nature, rather the concept of abstract number is a mental representation of the quantity of objects in nature that are then calculated before manipulating the object. Vygotsky (1997b) noted that, “In mathematics we forget all these analogies (to reality) and that is why its abstractions turn into something enigmatic.” (p. 249)

Research on the development of mathematics in all four genetic domains is available and has come into particular attention with the discovery of the brain areas associated with the mathematical disorder of dyscalculia. Cross cultural research and analysis on the performance of children in mathematics is an international topic of discussion. For these reasons, mathematical development of the concept of abstract number was used as an application to portray the use of Vygotsky's genetic method of analysis.

2.6 Summary

This literature review explored Vygotsky's cultural-historical theory to understand its origin and several of its foundational concepts. Previous scholars, such as Geertz (1973) and Wertsch (1985), have suggested amendments to the theory that speak to the dialectical relationship between nature and culture in each of the genetic domains. Advancements in technologies since Vygotsky's time include new mediational means for research and data generation in regard to Vygotsky's cultural-historical theory as well.

The first section of this chapter described Lee's (1985) analysis of Marx's influence on Vygotsky's work. He identified four similarities, namely: 1) the hierarchal levels of human development that Vygotsky labelled the natural and cultural lines; 2) the idea that human consciousness is a product of practical activity, which Vygotsky translated into culturally mediated tools; 3) the interpretation of Marx's dialectical relationship as Vygotsky's interfunctional relationship between psychological processes, and; 4) the interpretation of Marx's holistic method of analysis as Vygotsky viewing development as revolutionary reorganization of consciousness (Lee, 1985). The second section expanded on Vygotsky's genetic domains and their explanatory principles. The explanatory principles are natural and sexual selection for the genetic domain of phylogenesis and decontextualization of mediational means for sociocultural

history (Wertsch, 1985). Potentially, explanatory principles may be posited for ontogenesis and microgenesis: first, the dialectical relationship between the natural and cultural lines for ontogenesis, and the interfunctionality of psychological processes for microgenesis (Luria, 1973; Wertsch, 1985). Section three reviewed Geertz's critique of Critical Point Theory on three points. His critiques were: 1) comparative animal studies cannot be used to compare mental capacities since hominids have evolved since the phylogenetic split from hominoids; 2) that cultural development predates *Homo sapiens* disputing the critical point of the origin of culture, and; 3) the assumption of psychic unity among all human groups has not been tested. Section four reviewed new technological mediational means that have provided researchers with tools to gain data that was not available to Vygotsky. The chapter concluded with a fifth section that provided literature for the use of mathematical development of the concept of abstract number as an application following the genetic method of analysis. With this overview of the literature review, this thesis proceeds to chapter three which articulates the methodology for this conceptual thesis.

Chapter Three: Methodology

Researchers are themselves social beings and are influenced by their society. Likewise, the North American research milieu and my experience in academia have influenced my research and, in effect, this conceptual thesis. As Gould (1981) succinctly stated, "Science, since people must do it, is a socially embedded activity. It progresses by hunch, vision and intuition" (p. 253). In this section, the influences of my research background that have led to this conceptual thesis are explored, followed by the methodology utilized for this conceptual thesis.

As a conceptual thesis, this thesis is a product of my analysis in collaboration with my research committee, and is especially influenced by my epistemological stance and exposure in academia. As Crotty (1998) stated, "epistemology bears mightily on the way we go about our research" (p. 9). Identifying the philosophical orientation, and more specifically, the epistemology driving research is helpful in making the researcher aware of the biases it entails. The epistemology in turn has a large effect on three other elements of research—theoretical perspective, methodology, and methods—which also contribute to the research process. It is through identifying the epistemology that the researcher becomes aware, in part, of its strengths and limitations. Therefore, it is vital to analyze my epistemological stance to inform the readers and more importantly so, myself, of the filters through which I gather, process, and interpret the texts included in this thesis.

This chapter consists of three sections. The first section includes researcher positionality and research history. The second section highlights the interdisciplinary research that has contributed to this conceptual thesis. The third section describes the procedure through which this conceptual thesis was undertaken. The chapter concludes with a brief summary.

3.1 Researcher Positionality

During my undergraduate degree in Behavioural Neuroscience at McMaster University in Hamilton, Canada, I felt the strong need to bring the findings of neuroscience out from inaccessible scientific journal articles and into society. The largest impact of implementing neuroscience research is on the developing human brain, and since the field of education is responsible for cultivating the next generation of citizens, I believed education to be the ideal field benefiting from the findings in neuroscience. Accordingly, I pursued my Master's degree at University of British Columbia in the Faculty of Education. The specialization of Human Development, Learning, and Culture, allowed me the freedom of conducting interdisciplinary research in my coursework. In the next step of my academic career, I look forward to joining the Center for Neuroscience in Education at the University of Cambridge for my doctoral degree combining the fields of neuroscience and education.

In my undergraduate education, the epistemological outlook I cultivated was that of objectivism, within the research tradition of positivism. The main objective of the degree was to develop critical thinking skills and be able to conduct and assess the validity and reliability of studies based on experimental methods. In objectivism, the relationship between the researcher and research is as minimal as possible, and researcher neutrality is often claimed. A separation between the knower and the known exists as objectivism characterizes the nature of knowledge as follows: the object has its own intrinsic meaning that is separate from consciousness. The sole purpose of the researcher is to discover, describe and explain what already exists (Crotty, 1998). In neuroscience, this seems to be the dominant drive for research. Each area of the brain is dominant for specific behaviours, and the aim of the researcher is to discover and match behaviour to brain region, termed localization of function. In objectivism, the view is that

research is progressing closer and closer to the truth, and that a universal truth exists separate from the researcher.

Switching disciplinary fields from the sciences to the humanities, from my Bachelors degree to my Masters degree, caused an epistemological dilemma in my research career and gave me a new outlook on the epistemology in which I was indoctrinated. I had skills and experience in conducting quantitative studies, but was very limited in performing qualitative studies. The introductory course on research methodologies in qualitative studies first questioned the epistemology we brought with us. It was here that I realised that the great divide did not arise from qualitative or quantitative methods, but rather the epistemologies of objectivism and constructionism (Crotty, 1998).

One epistemological position counter to objectivism is constructionism. Constructionism views truth as the result of experiences and interactions with the environment. Meaning is constructed through these experiences, and does not lie inherently in the object itself. The object itself is nonexistent without human consciousness making meaning of it (Crotty, 1998). Social constructionism is a slight modification and states that humans are social beings, and are influenced by the meanings of social realities constructed by the society to which they have access. Socially constructed meanings provide the means to understand objects that exist regardless of human consciousness (Crotty, 1998). This epistemological stance is consistent with Vygotsky's concept of semiotic mediation, in that objects and the environment are perceived through the socially constructed meaning of the object.

The epistemological stance I have adopted is that of social constructionism. Natural and physical entities exist regardless of human consciousness, but the meaning of these entities is socially constructed and shared among people and generations. With my education in

neuroscience, I do believe the brain exists inherently, however, the development of human consciousness and what we know, or choose to know, about the human brain is influenced by socially constructed meanings. This epistemology is commensurable and consistent with Vygotsky's cultural-historical theory.

3.2 Interdisciplinary Research

To analyze psychological processes across the genetic domains, interdisciplinary review and research are required. As Wertsch (1991) stated, "we need to reformulate the questions we ask so that disciplinary and sub disciplinary integration will be a natural, or even necessary outcome" (p. 4). The literature review conducted in this paper is interdisciplinary. For example, in the domain of phylogenesis, research requires archaeology, anthropology and evolutionary biology. Likewise, in the domain of sociocultural history, research looks to the fields of cultural anthropology, history, sociology, communication, and linguistics. For ontogenesis and microgenesis research in psychology and neuroscience are predominant. Therefore, interdisciplinary research is required in order to be able to conduct research using the genetic method of analysis. A holistic approach to the development of any psychological processes requires an "interdisciplinary" approach, as research from various "disciplines" can and should be collaborated to understand internal workings and causal dynamics of the psychological processes under study (Wertsch, 1991).

"Vygotsky was a polyphonic thinker who wove a subtle tapestry of ideas carefully chosen from the intellectual fabric of his times" (Lee, 1985, p. 66). The genetic analysis conducted in this conceptual thesis was only possible with my exposure to courses in the fields of anthropology, psychology, neuroscience, social science and education. The courses I took in my undergraduate and graduate education provided an introductory base in the fields of biology,

anthropology, psychology and sociology. This conceptual thesis is a culmination of the courses and research I have been exposed to thus far. With this brief introduction of the researcher's background, the next section describes the methodology followed for this conceptual thesis.

3.3 Procedure

The conceptual framework for this thesis was laid during a graduate course on Vygotsky's cultural-historical theory. The course introduced me to a core text of the translated works of Vygotsky (Vygotsky, 1978) and interpretations, extensions, and applications of his work (e.g., Wertsch, 1985). The seminar discussions with my lens of neuroscience led to the overarching research question of: What does research on the neurological underpinnings of human development suggest regarding a dialectical relationship between nature and culture in each genetic domain—phylogenesis, sociocultural history, ontogenesis, and microgenesis? The following procedure lays out the steps taken to conduct this conceptual thesis.

Step one: My research committee guided me to the anchor texts. The anchor text by Cole (2007) was foundational in exemplifying the dialectical relationship between the natural and cultural lines across phylogenesis, and sociocultural history, in ontogenesis. The article by Lee (1985) explored the influence of Marx in Vygotsky's work. Key scholars of the field, most notably Michael Cole, forwarded their suggested readings. Support from the research committee provided additional resources and diversified the suggested readings and topics of this conceptual thesis.

Step two: I reviewed the anchor texts and cross-referenced the reference lists. For example, Geertz's (1973) critique of Critical Point Theory of evolution was an amendment suggested by Wertsch (1985).

Step three: I identified more potential texts from the reference lists from step two. Literature lists for each of the key concepts were created and continued to expand over the course of this conceptual thesis. The key concepts included a background of Vygotsky's cultural-historical theory, a separate list for each of the four genetic domains, amendments to Vygotsky's cultural-historical theory suggested by other scholars, possible research applications of the amended theory, and, finally, methodology. The larger conceptual thesis was divided into five projects, namely the dialectical relationship in the neurological underpinnings of development in the genetic domains of 1) phylogenesis, 2) sociocultural history, 3) ontogenesis, 4) microgenesis and finally, 5) the application of the dialectical relationship in the development of the decontextualization of abstract number, across the four genetic domains.

Step four: Then, I undertook a thorough reading of the texts, identifying the main concepts of the text.

Step five: Selection of the texts included was based on the criteria that the text expanded upon key concepts of the conceptual thesis. The selection criteria were that the text was based on the neurological underpinnings of human development and the text related to the dialectical relationship between nature and culture.

Step six: A deeper reading of these selected texts, and how the text contributed to the conceptual thesis, was conducted. Notes were coded according to the section of the conceptual thesis toward which they contributed.

Step seven: A database search was conducted to review the literature for each of the genetic domains based on the selection criteria.

Step eight: A database search was conducted to review the interrelationships between genetic domains based on the selection criteria.

Step nine: A database search for the application of the amended method on the development of psychological processes of the decontextualization of abstract number.

Step ten: The number of texts possible for inclusion multiplied significantly, and the committee and I decided to reduce the focus to research in the field of neuroscience over the other potential disciplinary perspectives.

A large database search was conducted using library and online resources. The database search was recursive, where suggestions from key scholars and committee members began the cycle of the procedures outlined above.

3.4 Summary

In this chapter, the researcher's positionality and the procedure followed for this conceptual thesis was reviewed. The epistemology of the researcher filtered the information gathering process, and so it was vital to determine the researcher's positionality. The researcher adopted the epistemological stance of social constructionism, which states that the meaning of social realities is socially constructed. This conceptual thesis called for interdisciplinary research that was made possible by the researcher's academic background. This chapter described the procedure to be followed in order to conduct this conceptual thesis. The next chapter addresses the research questions related to the genetic method.

Chapter Four: Conceptual Analysis

Vygotsky stated that the relationship between nature and culture is a dialectical one, however, he only explicated this dialectical relationship in the genetic domain of ontogenesis. Even here, development in the natural line occurred first and became less significant after the development of speech and language as the primary means of mediating the cultural line took over (Wertsch, 1985). The purpose of this conceptual thesis was to apply the dialectical relationship of nature and culture across all the domains of the genetic method, with a focus on the neurological underpinnings of human development.

This chapter is organized by genetic domains, highlighting the dialectical relationship between nature and culture, with a focus on the neurological underpinnings of development. For the genetic domain of phylogenesis, Vygotsky stated Darwin's theory of natural and sexual selection as the explanatory principle of development (Wertsch, 1985). This implies that in phylogenesis, the development of the natural line is predominant, while development in the cultural line is overlooked. In this chapter, the development in the cultural line that influenced the developmental history of *Homo sapiens* is stated. For the genetic domain of sociocultural history, Vygotsky conceptualized the decontextualization of mediational means as the explanatory principle of development (Wertsch, 1985). This implies that in sociocultural history, development is exclusively in the cultural line. In this chapter, the development in the cultural line that influences the developmental in the natural line is explored. For the genetic domain of ontogenesis, Wertsch (1985) stated that Vygotsky implied the dialectical relationship between the natural and cultural lines of development may be the explanatory principle. Even so, Vygotsky theorized that natural development occurred through infancy until the child was able to use language, after which cultural development took precedence. In this chapter, current research

that provides evidence for development in the natural line that occurs well past infancy and much before infancy is analyzed. For the genetic domain of microgenesis, there is early evidence to show that Vygotsky may have been examining interfunctional relationships between psychological processes as an explanatory principle of development (Luria, 1973). In this chapter, the dialectical relationship between the natural and cultural lines is investigated in relation to research in the neurosciences.

This chapter contains four sections elaborating the dialectical relationship between nature and culture with a focus on the neurological underpinnings of development for each of the genetic domains: 1) phylogenesis, 2) sociocultural history, 3) ontogenesis, and 4) microgenesis. Each of the four sections is followed by an integration of the findings into cultural historical psychology. The fifth section is on the influence of breast milk on cognitive development, as an example highlighting the interrelatedness of the genetic domains and the dialectical relationship between nature and culture. The chapter ends with a summary of the conceptual analysis.

4.1 Phylogenesis

One of the key defining characteristics of *Homo sapiens* is the relative brain size to body size, with the development of the frontal lobes as a major contribution to increased brain size. What may have caused the sudden expansion in brain size? There are two hypotheses that look to the culture of hominids that may have led to the increase in brain size. Namely, the Hunting Hypothesis proposed by Ardrey in 1970 and the Social Brain Hypothesis proposed by Dunbar in 1998.

Biological anthropologists argued that the increase in relative brain size is responsible for the *Homo* genus surviving, while other hominid species became extinct (Semendeferi, Damasio, Frank, & Van Hoesen, 1997). Since it is impossible to get the actual measure of the brain sizes of

our extinct predecessors, biological anthropologists study the fossil remains and estimate the brain size of our ancestral species based on the cranial capacity, which is the vessel of the brain. The cranial capacity of chimpanzees, which is a close hominoid relative to the hominids, is 395cm^3. The cranial capacity of *Homo erectus*, the predecessor of *Homo sapiens* is 1050cm^3. While the *Homo* genus' contemporary *Australopithecus* genus, reached the cranial capacity of only 500cm^3. Therefore, the relative brain size of the *Homo* genus is believed to be the evolutionary change of the *Homo* genus evolving into the current day *Homo sapiens* with a cranial capacity of 1230cm^3, while the *Australopithecus* genus became extinct (Pilbeam & Gould, 1974). What may have caused the sudden expansion in brain size? Archaeological anthropologists look at the culture of the early *Homo sapiens* through the cultural artefacts they left behind, as possible evolutionary pressures that led to increased relative brain size that was advantageous to the *Homo* genus.

The Hunting Hypothesis (Ardrey, 1970) postulated that the group hunting strategy of *Homo sapiens,* which led to larger group sizes, required the use of language for social cohesion, and planning for hunting and group sustainability. Thus, the increased cognitive demand of planning and the use of language resulted in the expansion of the species' brain size, particularly of the frontal lobes (Ardrey, 1970). A proposed reason that the group sizes increased is because the hunting strategy adopted by *Homo sapiens* increased the overall efficiency of the group, allowing them to support larger groups. The Social Brain Hypothesis is supported by the close statistical relationship between the relative brain size and group size in the evolutionary history of *Homo sapiens (*Aiello & Dunbar, 1993). Looking at fossil records and cultural artefacts left behind, archaeological anthropologists estimated that the average group sizes of chimpanzees is 60 members, while the *Australopithecus* genus reached an estimated maximum group size of 70

members (Aiello & Dunbar, 1993). The *Homo erectus* had group sizes of approximately 115 members, while *Homo sapiens* have group sizes of about 160 members (Aiello & Dunbar, 1993). These numbers are positively related to the cranial capacities mentioned previously in this section.

4.1.1 The Hunting Hypothesis

The Hunting Hypothesis (Ardrey, 1970) proposed that the diet and the hunting strategies of hominids led to the increase in brain size and the subsequent survival of the Homo sapiens species. Before the Hunting Hypothesis, there was the Scavenger Hypothesis and the Vegetarian Hypothesis. The Scavenger Hypothesis suggested that hominids scavenged for meat from the kills of expert hunters such as lions, leopards and tigers. This hypothesis was refuted by the simple fact that if hominids could not hunt large prey, then it was not possible to compete with expert hunters (Ardrey, 1970). The Vegetarian Hypothesis suggested that meat was not a considerable source of nutrition and that hominids relied on vegetation for food. This hypothesis was refuted by archaeological finds of animal remains, butchering sites, and an examination of coprolites (fossilized feces) that did not support a vegetarian diet. Also, the climate change in the Pliocene era led to the withdrawal of forests, and the hominid migration into the savannah. Given the vegetation in the savannah, seeds were the only available food. However, the purpose of seeds is to pass through the digestive system to allow for germination at a foreign site. The nutritional value of seeds is only obtained through the process of cooking, but hominids did not have access to controlled fire until the *Homo erectus* (Ardrey, 1970). Therefore, the Hunting Hypothesis remains.

The hominids migration into the savannah, away from the forests was a move that had large implications on the evolutionary history of *Homo sapiens* (Ardrey, 1970). To survive in the

savannah, hominids needed weapons in order to compete and survive amongst expert hunters and runners like leopards and lions. In order to use weapons, hominids required free hands and could not walk on all fours. This constraint led to the evolution of bipedalism in hominids. However in order to hunt with hand held weapons before the evolution of long distance weapons, hominids had to use group hunting strategies to survive. These group hunting strategies called for cooperation and interdependence between hunters (Ardrey, 1970). According to Engels, the use of hands for tools led to work and, because of this work, the need to speak to each other arose (Luria & Vygotsky, 1992). The sharing of food amongst individuals allowed nursing mothers primarily to care for infants. The group hunting strategy also required communication between hunters through silent body language, and gestures, which may have been the evolutionary precursors to the development of language (Ardrey, 1970).

It was not until the evolution of the *Homo erectus* that hominids had access to controlled fire 300 000 to 400 000 years ago (Ardrey, 1970). Even so, the *Homo erectus* species could only collect and use fire from bush fire to their advantage. This limited the environment and geography of the hominids to near the equator because of the climate (Ardrey, 1970). With the access to controlled fire and the warmth it provided, hominids could migrate further away from the equator. The use of fire played an important role of the survival of hominids through the Ice Age.

Neanderthals had a larger relative brain size than the *Homo sapiens* and, yet, they became extinct. Interestingly, the weapons of the hominids during this period were "unnecessarily beautiful" through their symmetry and polished nature, and this may denote the hominid brain's inclination towards art (Ardrey, 1970). This suggests that the *Homo sapiens'* brain was more organized than the Neanderthal's. Looking at the cranial structures of the fossil remains,

Neanderthals had a flat and sloping forehead but a larger base, implying that the prefrontal cortex—the seat of executive functions, such as inhibition and planning—was not increasing in size as was the case with *Homo sapiens'*. The ultimate evolutionary advantage *Homo sapiens* had over Neanderthals was the evolution of long distance weapons (Ardrey, 1970). With the invention of spears, bows and arrows, *Homo sapiens* could overcome the constraint of bipedal running speed and hunt animals from a distance and at higher speeds.

Ardrey's (1970) proposition was that, "Our humanity is not the consequence but the cause of our becoming human beings" (p. 71). Through the evolution of *Homo sapiens* described in the Hunting Hypothesis, it is plausible to state that cultural tools—such as weapons, fire and long distance weapons—allowed for the survival and evolution of the hominids into the *Homo sapiens* species. Had the cultural tools not been invented, *Homo sapiens* may not have survived in their environment because of natural forces such as the Ice Age. Without weapons, *Homo sapiens* would not have survived the migration to the savannah, competing with expert hunters such as leopards. *Homo sapiens* would not have been able to migrate away from the equator or survive the Ice Age without the warmth provided from fire. Fire also led to the new social practices around cooking, allowing *Homo sapiens* to ingest a larger variety of food, such as seeds, which would not have been digestible or nutritional otherwise. Without long distance weapons, *Homo sapiens* would not have been able to hunt large animals and have an evolutionary advantage over the Neanderthals (Ardrey, 1970). For these hypothesized reasons, the development in the cultural line of hominids provided the affordances for the development in the natural line of *Homo sapiens*.

4.1.2 The Social Brain Hypothesis

Dunbar (1998) pointed out that the evolutionary enlargement of the brain is metabolically expensive; the brain is only 2% of the body taking up 20% of the energy intake. Therefore, there must be an evolutionarily valid reason for the enlargement of the brain in primates. Dunbar observed that primate groups were particularly social, and developed both social coalition, as well as tactful deception. Hence this hypothesis, which was initially named the Machiavellian Hypothesis, is now termed the Social Brain Hypothesis.

Finlay and Darlington measured brain size relative to body size, which became the norm of measuring brain sizes across species (as cited in Dunbar, 1998). This is the only form of measurement that can be used with extinct species that have left fossilized remains, since it can be assumed that the cranial size is relative to the brain size. However, as noted before Neanderthals had larger brains than Homo sapiens and it is hypothesized that the advantage of the Homo sapiens' brain is better organization and the enlargement particularly of the prefrontal cortex. Dunbar (1998) and Reader and Laland (2002) argued the same, stating that whole brain size cannot be compared, but rather parts of the brain should be compared.

Dunbar (1998) statistically compared the brain size of 24 species of living anthropoid primates with the group sizes as the dependent variable. He found a positive relationship between the brain size of the neocortex and the group size. To further tease apart this relationship, Dunbar found that the hippocampus—brain area associated with memory—was not correlated with the group size, nor was the visual cortex. Instead it was the prefrontal cortex that was related to group size. Biologically, the constraint of group sizes did not lie in visual recognition or memory since humans are able to remember 2000 faces, but have group sizes of only 150. Dunbar (1998) postulated that the purpose of an enlarged brain is not to merely

remember, but to keep track of social relationships and connections, and thus 150 members is the upper limit of the number of relationships *Homo sapiens* can have.

Another relationship between group size and primate species that Dunbar (1998) noted was the juvenile period of the young. Group size was not related to gestational period, reproductive lifespan or lactation, but rather the juvenile period in which young are mentored by the adults in the group. In other primate species, the bulk of brain development occurs in the womb, while for *Homo sapiens*, it is not till the age of one year that the child's brain has developed to the level of other primates at birth (Gerhardt, 2004). Humans have the longest juvenile periods during which copious amounts of learning must occur in order for the individual to survive. The mother has a biological constraint of only being able to nourish the growing brain both metabolically and anatomically. The brain is metabolically expensive and so the unmanageable metabolic load of a developing brain on the pregnant mother has led to the evolutionary adaptation of the brain developing after gestation and birth (Gerhardt, 2004). Another physical anatomical constraint is the size of the birth canal and the girth of the skull circumference in *Homo sapiens*. The brain development occurring outside the womb also allows for social interactions to play a role in the development of the brain. The brain developing outside the womb with much more stimuli, leads to the social context having a direct impact on brain development in the natural line (Gerhardt, 2004).

As the Social Brain Hypothesis suggests, in the developmental history of the human species, the need for social relationships and interactions may have led to the evolution of an increased neocortex (Dunbar, 1998).

4.1.3 Integration into Cultural-Historical Psychology: Phylogenesis

Taking both the Hunting Hypothesis and the Social Brain Hypothesis into account, it is plausible to state that the developmental history of *Homo sapiens* was not purely reliant on the development in the natural line. Vygotsky stated the explanatory principle for phylogenesis as natural and sexual selection, however within the domain of natural and sexual selection, cultural tools and social interactions had a role to play.

The question in the field of neuroscience is whether brain development occurred first, providing the affordances and constraints to behavior, or whether the behavior occurred first and, thus, required strengthened and enlarged brain areas. Brain sizes of hominids are based on the fossil evidence of cranial capacities of the skulls that have survived natural elements. A method called radiometric carbon dating is used to measure the time period of the fossils. This method can determine the number of years ago the fossil remain existed, with a standard deviation of +/- 500 years. Therefore, archeologists cannot rely on the dating of the skulls and correlate it to the cultural tools, to determine which came first since the method and technology does not allow for such precise accuracy. Added to this, radiometric carbon dating is only accurate up to 50, 000 years ago, which does not cover the period of early hominids (Fairbanks et al, 2005). The puzzle of whether brain development led to cultural development, or vice versa, is complicated by the evolution of a brain that develops post partum with social interactions and culture providing the input for the developing brain.

Ultimately, development may have occurred simultaneously making nature and culture irreducible. The difficulty in making causal statements—for example that the cultural tools of weapons and fire, or the social practices of coalition and tactful deception, are the cause of evolutionary adaptation of enlarged brain sizes in hominids—highlights the dialectical

relationship between the natural and cultural lines of development. It is only for analytic purposes that development is divided into the categories of natural, or biological, and the cultural, or social. However, in reality, these divisions are problematic at best; since development in the natural and cultural lines are so intertwined, it may be artificial to separate them.

4.2 Sociocultural History

In the genetic domain of sociocultural history, the explanatory principle suggested by Vygotsky was that of the decontextualization of mediational means. The decontextualization of mediational means is the ability of human beings to have mental representations of objects, without requiring a concrete object or context through the use of culturally mediated tools (Wertsch, 1985). Given the way Vygotsky defined the explanatory principle, the development in sociocultural history was almost exclusively in the cultural line. However, as the Hunting Hypothesis (Ardrey, 1970) demonstrates, cultural practices have also influenced the development in the natural line reiterating the dialectical relationship in development. At a more societal level, this section examines the Neurodevelopmental Hypothesis of the Flynn Effect and specialized professions, to emphasize the dialectical relationship between the natural and cultural lines in the genetic domain of sociocultural history, focusing on the neurodevelopmental underpinnings of psychological processes.

4.2.1 The Neurodevelopmental Hypothesis of the Flynn Effect

Before addressing the Neurodevelopmental Hypothesis of the Flynn Effect, the notion of intelligent quotient (IQ) must be discussed. Binet formulated the IQ test at the request of the educational system to find students who could benefit from extra help in the classrooms (Gould, 1981). Accordingly, Binet collected a few everyday tasks and chores that were performed and made them into a test that provided numerical data for statistical purposes. Though he argued

that this test should not be used to rank students, and that it was not a method for reifying something called "intelligence," American psychologists translated the test and presented it as a means of measuring an innate attribute called intelligence. The resulting version of the Stanford-Binet IQ test has been challenged on that grounds that the validity of is highly questionable, particularly with scores being correlated directly to intelligence (Gould, 1981). Two of the psychologists who originally used the tests as the basis for assessing immigrants and measuring people living in poverty recanted their research results although this was after having a direct effect on the Immigration Act of 1924 in the United States.

Vygotsky (2011) challenged the use of intelligence tests of any kind and argued that scores on IQ tests do not coincide with the relative learning that occurs in school. He observed that the IQ scores tested at the beginning of the school year did not correlate with relative achievement at the end. Rather, he found an inverted relationship: students with the highest IQ scores improved the least, while the students with the lowest IQ scores improved the most. Vygotsky questioned whether the absolute scores were more important, or whether the relative achievement in scores reflected learning and the success of the school year. In other words, is the child who enters with a high score and maintains a stellar average benefiting more or less than the child who enters school with a lower score but continuously improves in achievement over the school year? In the same study, Vygotsky (2011) found that the zone of proximal development—what a child was capable of achieving alone versus what the child could achieve with guidance when required—was better correlated to school achievement than static IQ scores.

With this background, the inclusion of studies of IQ are interpreted cautiously, since they also show effects on the development of the natural line of brain development, independent of the IQ tests. For example, the Neurodevelopmental Hypothesis of the Flynn Effect is included as

it provides an example of how sociocultural history of a particular society may influence brain development. The emphasis of this section is the influence of universal formal education and the downward shift of the mathematics curriculum on the prefrontal cortex, rather than on the effects it is hypothesized to have on IQ scores. Likewise, other studies included in this conceptual thesis with IQ tests may also show development in the natural line, which is the focus of this conceptual thesis, rather than the results correlated with IQ scores.

Over the past century, a consistent increase in the population mean of intelligence quotient (IQ) scores of Americans has been noted (Blair et al., 2005). For example, on the Wechsler scale, which tests crystallized knowledge—defined as the ability to use life skills and knowledge—researchers have noted a 20 points increase within 60 years. Even more dramatic is that on the Raven's Progressive Matrices Test, which tests fluid intelligence—defined as the ability to problem solve and logical thinking—there has been an increase of 20 points within one generation. The population mean increase in IQ points is too drastic to be explained by genetic hereditary, and yet this increase affects the whole population. Therefore, the factor causing this phenomenon is one that influences the proximal environment and affects a large proportion of the population. The influence should also be one that intensifies historically, since the population mean IQ scores have been progressively increasing. Interestingly, the distribution of IQ scores within a cohort is normally distributed, yet it is when the population mean IQ scores between cohorts are compared that the Flynn Effect is found. This suggests that the factor causing the Flynn Effect has a higher influence between cohorts, than it does within a cohort. What is the factor that satisfies all these requirements? Blair and colleagues (2005) examined the neurological underpinnings of intelligence to explore this further.

Studies in neuroscience note that the performance on fluid cognitive skills is a function of the prefrontal cortex (PFC). Activation in the PFC is noted when participants of neuroimaging studies perform tasks associated with fluid intelligence. Patients with PFC brain injuries perform poorly on the Wechsler Scale, which tests fluid intelligence, but perform normally on the Raven's Progressive Matrices Test, which tests crystallized intelligence. Because of the neuroplasticity of the PFC, its structure and function develops and strengthens with age and experience. As the authors note, "Taken together, evidence indicating that the PFC is the seat of fluid cognitive functions and undergoes protracted postnatal development suggests that population wide influences on prefrontal skill acquisition between cohorts would lead to increasing population mean IQ as observed by Flynn (1984, 1987)" (Blair et al., 2005, p. 97).

A meta-analysis cited in the article, looking at 50 naturalistic observations of schooled and non-schooled populations of children comparable on other extrinsic factors, showed on average a 0.3-0.6 IQ point increase for every year of schooling attended. Based on the findings of this study, the authors looked at the historical school enrolment demographics in America. In the 1890's, 80% of children were enrolled in elementary and secondary education, while less than 10% were enrolled in kindergarten. During World War II, enrolment in elementary and secondary education became universal, while kindergarten enrolment drastically rose. By 1980, even kindergarten enrolment had become universal, while enrolment in preschool (3-4 years old) also began. Hence, the earlier enrolment and universal access to formal schooling meant that children were spending more years in school, and thus showing an incremental increase in IQ scores, as supported by the meta-analysis study (Blair et al., 2005). However, why has the Flynn Effect continued after 1980, when universal enrolment in kindergarten had already been reached? For this, the authors turned to the evolving mathematics curricula.

Blair and colleagues (2005) stated that elementary mathematics is the subject in education that focuses on fluid cognitive exercises the most. Supporting evidence comes from neuroimaging studies where PFC activation has been noted in participants performing mathematics tasks. Also, students with learning disabilities perform poorly on both mathematics tasks, as well as fluid cognitive tasks. However, the mathematics curricula were not always focused on fluid cognitive skills. In the early 1900's, young children from kindergarten to grade 2 were not exposed to mathematics as it was assumed that basic literacy skills were required before concepts of mathematics could be taught (Blair et al., 2005).

With the visual representation of mathematics beginning in the 1930's, which focused on pattern recognition and pattern completion, literacy was no longer a pre-requisite and so, mathematics could be exposed to younger children. This “New Math” required students to hold these complex operations in their working memory, thus exercising the PFC (Blair et al., 2005). The mathematics curricula started to shift downward in age and grades, particularly in geometry. As the authors summarized, "Currently, young children regularly engage in visual-spatial problem solving associated with prefrontally based working memory functions that their grandparents' generation would not have been exposed to until the seventh or eighth grade and that their great-grandparent' generation may not have been introduced to at all" (Blair et al., 2005, p. 102). Taken that the PFC is the seat of fluid cognitive tasks and is developed through experience because of its neuroplasticity, the authors proposed that the downward shift of the evolving mathematics curricula played a role in the Flynn Effect, and continues to do so (Blair et al., 2005).

4.2.2 Specialized Professions

Another form of sociocultural history influencing development in the natural line is that of specialized professionals, such as musicians and taxi drivers, who have enlarged brain areas related to the function in which they specialize. For example, London taxi drivers who go through gruelling tests for licensure have larger anterior right hippocampus than others and this area of the brain is correlated to spatial navigation (Maguire et al., 2006). Likewise, professional musicians who practice regularly have larger motor, auditory and visuospatial brain areas than those who practice less or are non-musicians (Gaser & Schlaug, 2003). Humans who become experts in the sociocultural tools they use repeatedly have brain areas associated with that function strengthened. This demonstrates the dialectical relationship between nature and culture in sociocultural history.

In the case of London taxi drivers, Maguire and colleagues (2006) looked at the PET scans of London taxi drivers who go through approximately three years of intensive training before receiving their licenses. The participants, London taxi drivers and control participants performed six tasks based on recalling and retrieving topographical knowledge and tasks that were non-topographical. PET scans conducted while they performed these tasks were compared to baseline measures. The results showed that London taxi drivers had a larger anterior hippocampus than the control subjects, which was compensated by a smaller posterior hippocampus than the control subjects. The anterior hippocampus is associated with encoding new memories, and was activated when the participants had to learn new routes. The posterior hippocampus is associated with retrieval, and was activated when the participants had to map out a familiar route (Maguire et al., 2006). This was a seminal study that was able to find structural brain differences correlated to specialized skills.

In the case of musicians, Gaser and Schlaug (2003) compared brain imaging scans of musicians to amateur musicians and non musicians. They found grey matter volume differences in the brain areas associated with motor, auditory and visuo-spatial functions. All the participants were right handed males, and the musicians played keyboards. The results showed a positive relationship of strengthened motor and somatosensory areas, premotor areas, anterior superior parietal areas, inferior temporal gyrus bilaterally, left cerebellum, left Heschl's gyrus, and left inferior frontal gyrus, with the keyboard skill level of the participants. Interestingly, they did not find a compensatory brain area that was smaller in musicians than non-musicians (Gaser & Schlaug, 2003). This study highlighted that repeated use of a specific cultural tool can strengthen the brain areas associated with that particular function.

Neuroscientific studies have concurred that infants are born with a preference for faces and visually seek stimuli with high contrast (Cole, 2007). The brain area associated with facial recognition is in the fusiform gyrus. Interestingly, this area is also activated when humans see objects that they are specialists in, for example alphabets, numbers (Cole, 2007; Pelaprat & Cole, 2011) birds or cars (Damon, & Lerner, 2008). This shows how a phylogenetically evolved trait of facial recognition adapts to cultural tools and signs by recognizing objects that humans are exposed to on a regular basis, reiterating the dialectical relationship between nature and culture in the genetic domain of sociocultural history.

4.2.3 Integration into Cultural-Historical Psychology: Sociocultural History

The Neurodevelopmental Hypothesis of the Flynn Effect (Blair et al., 2005), and the correlated strengthening of brain areas associated with functions through cultural tools in which individuals are experts, shows the close dialectical relationship between nature and culture in the genetic domain of sociocultural history. Vygotsky used the explanatory principle of

decontextualization of mediational means and although he implied this genetic domain to be development exclusively in the cultural line, studies and findings stated in this section show the repercussions of cultural tools on the development in the natural line.

The Neurodevelopmental Hypothesis of the Flynn Effect, suggested by Blair and colleagues (2005), stated that the social practice of universal education and the downward shift of mathematics curricula are a plausible cause of the Flynn Effect and the strengthening of the PFC. The cultural tools and signs shared from one generation to the next not only lead to development in the cultural line, but can also influence the development in the natural line for that society. Mathematics itself is a cultural tool that, once internalized, can operate as a sign. Numbers are a system of signs that allow humans to mentally represent and calculate objects in their environment. This system has been formalized through the means of mathematical language and curricula to facilitate communication between humans. The hypothesized effect on brain development highlights how sociocultural history, or more specifically, culture, can impact brain development.

Neuroscience studies finding strengthened brain areas associated with specialized professions highlight how the repeated use of cultural tools and signs can influence brain development. In the case of London taxi drivers, spatial maps are cultural representations used to enable navigation (Maguire et al., 2006). Once internalized by taxi drivers, over repeated use, the effect on the natural line of brain development is evident. In the case of musicians, musical notation, which is both read and heard, and the use of keyboards, has been internalized by musicians and the influence on brain development in the visuospatial, auditory, and motor areas is evidenced in studies (Gaser & Schlaug, 2003).

The question in neuroscience studies of whether the brain development occurred first, or whether the behaviour strengthened the particular brain areas, re-emerges in the neuroscience studies of specialized professions. Although it is evident that London taxi drivers have a larger posterior hippocampus associated with spatial navigation, and musicians have larger visuospatial, motor and auditory areas, the question arises whether these areas were strengthened solely based on the repeated use of the cultural tools and signs, or whether individuals were inclined to these professions in the first place because of their specific capacities linked to larger brain areas. It is unfeasible to obtain brain images of a random population, follow the individuals as they develop their professions, and then determine whether the brain areas were a cause or a result of the specialized professions. This difficulty in providing a causal statement, reiterates the dialectical relationship between the natural and cultural lines of development, as well as the artificial nature of separating them for analytic purposes.

4.3 Ontogenesis

It is only in the genetic domain of ontogenesis that Vygotsky emphasized a dialectical relationship between the natural and cultural lines of development. Even so, he implied that they developed in relative isolation, in which development in the natural line takes its course until the child is able to use language, after which the child's development occurs largely as a result of the cultural line (Wertsch, 1985). In this section, studies looking at how culture influences nature in development are explored: 1) when the child is still developing in the womb and 2) beyond adolescence. The effects of stress and the environment's direct impact on biology suggest a dialectical relationship between nature and culture in the genetic domain of ontogenesis.

4.3.1 Before Infancy

Vygotsky implied that development in the cultural line took over development in the natural line after the child began using speech (Wertsch, 1985). Studies since his time, with the aid of advanced technology, show that development in the cultural line can occur even before birth in the prenatal environment. These studies are explored in this section.

4.3.1.1 Teratogenic Effects and Environmental Stressors

Teratogenic effects are caused by toxins to which the foetus is exposed in the womb through the mother's consumption and environmental exposure. The most common teratogens are alcohol, tobacco and cortisol through the mother's elevated stress levels. Toxin exposures are sadly avoidable teratogens that have drastic effects on the developing foetal brain. Toxin exposures during early development are the cause of neurodegenerative diseases and the decline of intelligent quotient (IQ) (Weiss, 2000). The exposure of the foetus to toxins is partly dependent on the social practices of the pregnant mother, and so the dialectical relationship between the mother's cultural influences on the foetus's development in the natural line is described in this section.

The placenta walls are lipid soluble and contain enzymes that alter toxins into metabolites that may be even more harmful to the developing foetus (Mednick, Cannon, Barr & Lyon, 1991). Different toxins may cause similar effects, however, an aggregate may have dire effects even if ingested in recommended doses. Latent toxicity is more complex; as demands, such as stress and aging increase, the consequence of the toxins is enhanced. Infants are further exposed to toxins through breast milk due to its lipid solubility, transmitting toxins in greater quantity (Weiss, 2000). These toxins diffuse into foetal lipid stores with slow release over a period of time, such that, results of substance abuse may appear much later. Substance abuse later in the gestation

period disrupts the formation of synapses in the central nervous system causing neurobehavioral abnormalities. Through binding to enzymes and, thus inhibiting, molecules, toxins cause malnutrition and premature death of cell division (Mednick et al., 1991).

Specific toxins, such as ethanol, have been studied more than others. Foetal alcohol syndrome causes learning disabilities as it alters the migration of neurons in the cortex and suppresses adhesion molecules by impairing gene expression, thus affecting the structure and function. Ethanol also effects the development of the neurotransmitter system, such as dopaminergic neurotransmitters known to affect schizophrenics as the Dopamine Hypothesis suggests (Weiss, 2000). Foetal alcohol syndrome also lowers birth weight and growth; an effect linked to autism (Nanson, 1992). Excessive neural migration, which occurs at six to twenty weeks, is a symptom of foetal alcohol syndrome (Weiss, 2000). The onsets of the some of the effects of ethanol also occur later in life (Mednick et al., 1991).

Tobacco exposure through smoking also occurs during pregnancy, with the national average in 2004 being 8.4% of pregnant women, and hence studied in depth (Anderson, Ebrahim, Floyd & Atrash, 2006). Carbon monoxide binds to haemoglobin inhibiting oxygen and causing foetal hypoxemia, a condition when oxygen is depleted in the blood. The nicotine levels in the foetus are much higher than that of the mother due to the volume to concentration ratio as is the case with most toxins (Weiss, 2000).

Stress causes the release of cortisol that permeates through the placenta and affects the brain development of the child (Gerhardt, 2004), and so cortisol can be considered a teratogenic effect, but is also an environmental stressor. Stress in the prenatal environment, as well as the postnatal environment, directly affects brain development and functioning in children and adults. When stressed, the hypothalamus alerts the pituitary gland that then signals the adrenal glands to

release the hormone cortisol. Over production of cortisol saturates the hypothalamus, and the receptors become insensitive to cortisol and cannot regulate its production. Cortisol stops regular body mechanisms such as growth, immunity, digestion and reproduction. This allows the body to focus its energy on the stressful factor in the environment. Extended levels of high cortisol lead to neuronal death, primarily in the hippocampus, which is associated with memory, and the overworked prefrontal cortex fails to regulate stressful social situations that trigger the release of cortisol (Gerhardt, 2004).

Infants rely on caregivers to manage their stress levels, which are primarily based on physical survival and ensuring needs are being met. Therefore, responsive caregivers who support the emotional and physical needs of the infant within a reasonable time allow the infant to develop optimally (Gerhardt, 2004). There is a critical period of the first six months in which infants develop the hypothalamus-pituitary-adrenal glands axis and the experiences infants have in this time sets the baseline of cortisol. A healthy infant with plenty of attention has more cortisol receptors in the hypothalamus allowing them to cope more easily with stress as adults (Gerhardt, 2004).

The stress level of the caregiver impacts the infant in many ways. If the caregiver is stressed, then it is likely that the caregiver is not emotionally available or socially engaged for the infant's needs. Also, when infants see happy behaviour, activation in the left frontal lobe is noted, while sad behaviour is known to activate the right frontal lobe (Gerhardt, 2004). Dilated pupils of the caregiver indicate they are happy, and this increases the heart rate of infants and the release of neuropeptide beta-endorphins into the orbitofrontal cortex, and dopamine into the brainstem that then reaches the prefrontal cortex. These neuropeptides and dopamine stimulate glucose and insulin, which aid in neuronal growth, while cortisol inhibits these neurotransmitters

and stops neuronal growth. The prefrontal cortex takes information from the sensory areas and subcortex, processes this information and regulates the subsequent output or behaviour. The prefrontal cortex wires itself to avoid situations that are not socially advantageous, such as crying in the vicinity of abusive caregivers. The orbitofrontal cortex is the brain area associated with emotion regulation, which only starts to develop from birth and is not fully functional till 18 months of age. After the development of the orbitofrontal cortex, the brain shifts to developing the left side of the brain, which is associated with language and processing. Thus, the caregiver ultimately needs to calm the right brain down to ensure that the infant is not stressed and cortisol levels are maintained (Gerhardt, 2004).

4.3.1.2 Prenatal Environment and Preferences

Studies since Vygotsky's time have looked into the prenatal environment and how that influences the child's development over the lifespan. An interesting finding in the field of child development is the preference for familiarity that infants inculcate from within the womb (Maurer & Maurer, 1988). This finding was revolutionary in understanding the perception of the foetus before birth. Since infants do not yet have the ability to communicate their knowledge and preferences to researchers by answering questionnaires, a method termed habituation was developed. When a stimulus is presented, the infants show signs of interest such as viewing the stimulus for a longer time, or sucking the pacifier at a faster rate. This allows researchers to analyze whether infants detect differences, as well as their preferences between the stimuli (Gopnik et al., 1999).

To study the sense of taste of the foetus in the prenatal environment, researchers injected amniotic saccharine and dye into the womb (Bradley & Stern, 1967). The independent variable was the amount of saccharine, and the dependent variable was the amount of dye in the mother's

urine. The higher the dye content, the less the foetus ingested the saccharine. They found that the foetus preferred sweet (Bradley & Stern, 1967). In another experiment pregnant women were either asked to consume carrots daily over their gestation period or not in the control group. The results showed that infants in the carrots group preferred the taste of carrots more than the control condition (Mennella, Jagnow & Beauchamp, 2001). After birth, infants soon start to prefer the taste of the native cuisine. This shows that the social practices of a specific diet, including food, food preparation, and taste, can be inculcated from within the womb even before the infant is born.

To study the auditory sense in the womb, researchers played certain genres of music or read the same story to the foetus through the womb (Maurer & Maurer, 1988). When the infant was born, researchers conducted a habituation task to test their preferences. They found that infants preferred the auditory stimuli they were exposed to within the womb. This finding extends to infants preferring the mother's voice, native music, and native language (Maurer & Maurer, 1988). These studies are empirical examples of how development in the cultural line begins even before birth and in relation to social practices and preferences in the mother's environment.

4.3.2 After Infancy

Vygotsky implied that after a child begins using speech, the force of development shifts from the natural line to the cultural line. However, it is apparent that biological maturation and brain development occur much past infancy. The age at which brain development stops has not been determined and is rather dependent on the maximum age of participants in the studies in the field. Neuroscience, which has primarily focused on development particularly in early childhood, is only beginning investigations in the field of gerontology.

Gogtay and colleagues (2004) conducted a brain imaging longitudinal study in which they used MRI scans with 13 children every two years for a period of 8-10 years. The MRI scans of children beginning at age four, documented their brain development until the age of 21. Seventeen sulci were traced and aligned across the MRI scans for each age group by an image analyst who was blind to the study. A reduction in grey matter reflects the increase in myelination in MRI scans. With MRI scans, Gogtay et al. (2004) created a time dependent average 3D model. Their findings showed that the grey matter in the dorsolateral prefrontal cortex reduces only at the end of adolescence, whereas the orbitofrontal region matures past 21 years of age (Gogtay et al., 2004). These areas, which are the latest to mature, are involved in executive functions, attention and motor coordination.

Courchesne and colleagues (2000) conducted a cross-sectional study looking at the MRI scans of healthy participants from 19 months to 80 years old. What they found was that the whole brain itself grew 25% between early childhood to adolescence. The grey matter consisting of neurons and synapses increased 13% between the ages of 6 to 9 years old, after which the grey matter increased at a lower rate reaching a plateau at 40 years of age. Grey matter again decreased 13% percent for the oldest participants of the study (Courchesne et al., 2000). In this study, a broad measure of grey matter was analysed. However, growth of neurons in specific areas of the brain, particularly the hippocampus has been noted throughout life (Erikson et al., 1998).

This section shows evidence of significant development in the natural line much beyond infancy and throughout life. Therefore, Vygotsky's de-emphasis on natural development is potentially problematic.

4.3.3 Integration into Cultural-Historical Psychology: Ontogenesis

Vygotsky emphasized a dialectical relationship between the natural and cultural lines of development in the genetic domain of ontogenesis, and Wertsch (1985) suggested this to be its explanatory principle. However, Vygotsky stated that development occurs primarily in the natural line, until the child begins using speech, after which development shifts primarily to the cultural line. Studies and findings that have been stated reveal that the influence of the cultural line is evident even before birth, in the womb, and that brain development in the natural line, surpasses infancy. The effects of teratogens and stress highlight the dialectical relationship between the sociocultural history and brain development across the lifespan.

Teratogenic effects indicate how the environment can directly impact the development in the natural line. Alcohol, tobacco and high levels of stress are aspects of social practices that are constructed by humans in relation to cultural objects, like having a glass of wine in the evening or smoking to reduce stress, as well as the meaning of participation or lack of participation in these practices. These social practices affect brain development. The social practices of the mother influence the development of the foetus in the womb, and that of the infant after birth. Smoking, drinking, and substance as social practices within which the mother participates exemplify how the cultural line of the mother may influence development in the natural line of the child. This dialectical relationship is more clearly highlighted in the case of environmental stress and the regulation of cortisol, which directly impacts brain development and functioning. These examples highlight the dialectical relationship between the natural and cultural lines, and that aspects of social practices and culture tools are not always positive and optimal to development (Cole, 1996).

4.4 Microgenesis

The genetic domain of microgenesis was not explored in detail by Vygotsky, although he was studying medicine and neuroscience in the last few years of his life. Luria continued the projects that Vygotsky and he began together; research of the dialectical relationship between the natural and cultural line of development of the human mind (Kotik-Friedgut, 2006). Since Vygotsky and Luria's time, new technology available has made a dramatic difference in making the working brain "visible." With advanced brain imaging technology invented since his time, research in the field of neuropsychology has grown by leaps and bounds. The explanatory principle for the domain of microgenesis is suggested here to be the interfunctional relationships between psychological processes, drawing on work by Luria (1973). Looking at the particular psychological disorder of conduction aphasia provides a means of explaining interfunctional relationships between psychological processes in context.

Luria (1973) relied mostly on patients with brain lesions as his subjects to understand the working brain. Although noted by Vygotsky and Luria in the 1930s, the 1970's were particularly known for a surge in attention to the "localization of function," with behaviors being associated with brain areas. Luria (1973) noted that it was possible to localize the function of elementary processes, but not of higher psychological processes because of the interfunctional relationships that are built upon each other over the course of ontogenesis. Different areas of the brain, even those far from each other, work in unison for the development of higher psychological functions. To understand this development it is necessary to unravel the elementary processes and functions that in unison result in higher psychological functions. Added to this complexity, Luria (1973) noted that cultural tools and signs are essential in establishing these interfunctional relationships between brain areas and functions. Kotik-Friedgut (2006) analyzed Luria's approach to

neuropsychology and suggested a universal principle: cultural tools establish functional connections. Therefore, neuropsychology must take into account cross-cultural differences and cannot take a Eurocentric approach that all human groups manifest the same behaviors associated with the same brain areas (Kotik-Friedgut, 2006). This was also the main concern of Luria, of the interdependence of the individual mind and culture, thus resulting in the new fields and terminology of cultural neuropsychology. However, according to Kotik-Friedgut, there is still a hesitation within cultural neuropsychology and the taboo of biological reductionism, resulting in studies examining the connections between education, neuropsychology and culture in a superficial manner. This ties into the critique of Geertz (1973) on the Critical Point Theory, that psychic unity amongst all human groups is an assumption that has not been tested.

Advanced brain imaging technology has allowed the field of neuroscience to study the development of the brain and how it functions. The first phase of brain development is synaptogenesis, which is thought to peak at the age of 12 for males and 11 for females (Blakemore & Choudhury, 2006). Synaptogenesis is the process of new synapses being formed and, thus, there is an increase in grey matter, which includes cell bodies and axons. Following this, synaptic pruning occurs. Synaptic pruning is the process of fine-tuning functional networks to increase efficiency, and it is a two-fold process. First, the neurons that are not used are pruned, which causes a reduction in the grey matter. Pruning unnecessary neurons limits random firing and, thus, makes the neural circuitry more efficient. Simultaneous to the pruning, axons are covered with myelin sheaths. Myelin sheaths are mainly composed of lipids and induct electricity. Myelin sheaths around axons allow cell electricity to bypass sections of the axon and jump to the next node of Ranvier, which is the section of axon that is not covered by myelin sheaths. This increases the speed of information processing. Due to the lipid content, myelin

sheaths have a whitish appearance, and constitute the white matter of the brain. Therefore, the reduction of the grey matter indicates synaptic pruning and making the neural circuitry more efficient by eliminating random neural firing, and the increase in white matter indicates myelination and the increase in information processing speed (Blakemore & Choudhury, 2006).

Neuroplasticity is a psychological incidence of neurons in the brain that are either rewired subsequent to damage, or strengthened because of extended practice. This principle was postulated by Hebb, who termed the phrase "cells that fire together, wire together" (Damon & Lerner, 2008). Neuroplasticity is dependent on external stimuli, and how the individual interacts with cultural tools and signs. For example, for children who are visually impaired and learn to read and write through Braille, the visual cortex becomes relatively small while the sensory cortex strengthens. Noted earlier, Vygotsky (1993) termed this phenomenon "compensation." Another example of neuroplasticity is that of specialists, such as musicians and London taxi drivers, who have strengthened brain areas because of their extended practice and mastery over a particular cultural tool.

Conduction aphasia is a language disorder in which patients are able to produce and comprehend speech, but are unable to repeat speech that is aurally heard (Damasio & Damasio, 1980). There are two main language areas with their functions being double disassociated. The Wernicke's brain area is on the left posterior superior temporal gyrus and is associated with comprehension of speech. The Broca's brain area is on the left anterior superior temporal gyrus and is associated with production of speech. Conduction aphasia is found in patients who have normal Wernicke's and Broca's areas, but have damaged the arcuate fasciculus, which are fibers that connect the Wernicke's and Broca's areas (Damasio & Damasio, 1980). Therefore,

conduction aphasia is an interesting phenomenon that demonstrates interfunctional relationships between psychological processes.

4.4.1 Integration into Cultural-Historical Psychology: Microgenesis

Neuroscience has focused on localization of function, and scientists conduct research to correlate brain areas with particular behaviours and functions. However, as Luria (1973) stated, it is important not to overlook the historical and social mode of development. Likewise, Johnson (2001), who conducted a review on neuroscience studies on the development of the human brain found that they were, "largely descriptive, with little attempt made to understand the functional causes and consequences of changes in neuroanatomy" (p. 479). One of the discoveries of the brain is the phenomena of neuroplasticity, which may be a potential extension of the explanatory principle of interfunctional relationships in the genetic domain of microgenesis. Neuroplasticity is an occurrence that describes the development of the brain and particular psychological processes, and relies on a dialectical relationship between the natural and cultural lines of development.

4.5 Integration of Genetic Domains: Breast Milk and Formula

Vygotsky's separation of the genetic domains and the differentiation of the natural line of development from the cultural line of development are purely for analytic purposes, since development is not so neatly categorized and segregated. As an example to show how the genetic domains are interrelated and integrated, an example is presented linking the replacement of breast milk with baby formula, a cultural tool. One of the first decisions a new mother makes is whether to breastfeed her infant or resort to formula feeding. The decision itself is influenced by many historical and social factors for the mother (Dennis, 2002). Breast milk has been associated with intelligence and cognitive development. To compare the benefits of breastfeeding versus

formula feeding, the evolutionary standpoint, the reasons for controversy, and the specific components of breast milk that may play a role in enhanced intelligence are investigated.

The developmental history of phylogenesis and the series of adaptations, from the animal kingdom to the *Homo sapiens* species resulting in the act of breastfeeding, is first analyzed. The first major adaptation of placental reproduction occurred with mammals, where the gamete was fertilized internally and after a gestation period, a live young was born (Maurer & Maurer, 1988). Accompanying this was the evolution of mammary glands where a maternal supply of nutrients was provided postnatally. The second significant adaptation leading to *Homo sapiens* was bipedalism. Although this was advantageous to the survival of our species, it came with the disadvantage of a narrower pelvis and birth canal. Added to this limitation, the brain size of our primate ancestors enlarged leading to the human brain, which is the primary distinguishing factor of the species *Homo sapiens*. Therefore, *Homo sapiens* brains' develop in the postnatal environment, allowing external factors to play a role in development. In our evolutionary history all surviving individuals were breastfed. Only fairly recently were babies fed formula, a new cultural tool and technological advancement that is an attempt to duplicate and/or improve on breast milk. Newborns have the innate reflexes of rooting, sucking and swallowing and, hence, the requirements to breast feed at birth. These two points imply that breastfeeding is an evolutionary adaptation of mammals (Maurer & Maurer, 1988).

This section is based on studies looking at the effects of breast milk on cognitive development. As noted earlier, the use of IQ studies in this conceptual thesis are used to demonstrate the dialectical relationship between nature and culture, and in this case, the effects of breast milk on cognitive development. The link between the compounds in breast milk and cognitive development was only discovered through studies finding differences in IQ scores. It

should be noted that only a difference of 15 IQ points or higher has clinical significance, and the studies noted in this section have differences of less than 10 IQ points (Maurer & Maurer, 1988), which although statistically significant, hold questionable practical value.

Previous findings suggest that breastfed infants have a higher IQ, when compared with standard formula fed infants. A longitudinal study testing the IQ of children, comparing and contrasting between those who were breastfed for different durations and those fed formula was conducted. The results show that children breast fed for a shorter period had 1-3 IQ points lower than those formula fed, which in turn were 3-7 IQ points lower than those breastfed for a longer duration, nevertheless these results wear off by the age of 5 (Rogan & Glade, 1993). The authors note that it might not specifically be the breast milk, but rather the interaction between mother and infant that increases the IQ. To control for this, a study was conducted (Lucas, Morley, Cole, Lister, & Leeson-Payne, 1992), where infants were either fed breast milk or standard formula, both through tubes, therefore eliminating social factors that may be connected to enhanced intelligence. The results confirmed that breast milk itself has an IQ advantage of up to 7.5 points, concluding that something in breast milk lacking in formula captures this effect. However, another variable that was not accounted for was the parental education, IQ and social class. Parental education and IQ might be passed on through the genes and it is noted that breastfeeding mothers usually have higher IQ and are more educated. Similarly the socioeconomic status of each family heavily impacts the child's exposure to a stimulating environment. A study controlling for confounds, such as maternal IQ and parenting skills, found non-significant results between the IQ of breast fed and formula fed infants (Jacobson, Chiodo, & Jacobson, 1999). It was also unusual to note that the selection criterion of mothers to participate in the study was a consumption of 11.8kg of fish over a 6 year period. These non-significant results and the high

ingestion of fish may hold the clue to the component involved in affecting the IQ level of children, as the component DHA is found both in breast milk as well as fish oils.

DHA (docosahexaenoic acid) and ARA (arachidonic acid) are omega-3 and omega-6 long chain polyunsaturated fatty acids (LCPUFA), which are responsible for neural growth, dendritic branching and neural regeneration post brain injury. From mid-trimester of gestation to the second year of life, a 10-fold increase of brain size is noted with 30-fold increase in DHA and 15-fold increase in ARA (Uauy, Hoffman, Mena, Llanos, & Birch, 2003). These high concentrations of DHA and ARA are also found in the central nervous system and the retina. Therefore the link between DHA and ARA with intelligence is one that is highly studied. With controversial findings, however, it remains unclear whether to supplement infant formula or not.

An article in the *Canadian Family Physician* clearly outlined the controversial findings of DHA and ARA's role in intelligence and whether the studies hold clinical importance. The article stated that DHA and ARA supplementation in formula is not recommended till further studies are carried out (Koren, 2000). Yet, the FDA approved DHA and ARA supplemented formula in 2002. How can this paradox be resolved? The problem lies in the fact that both DHA and ARA are metabolized by the same enzyme, hence a perfect ratio has to be administered to ensure optimal development. A study by Uauy and colleagues in 2003 compared infants that were either fed breast milk, standard formula, DHA supplemented formula or DHA and ARA supplemented formula. The findings suggest that the standard formula group performed poorer on IQ than the other three groups, however the group supplemented only with DHA were found to have poorer verbal IQ scores than those supplemented with DHA and ARA, and the breastfed group. Another factor leading to the controversial findings is due to the dose-response relationship where insufficient levels of DHA and ARA do not cause a significant advantage in

IQ scores as seen in the study by Rogan and Glade (1993), cited previously. How much breast milk is enough? A study in 2002 looked at the relationship between the duration of being fed breast milk, and the correlation to IQ scores as adults. The results show that there is a positive relationship between the duration of being breast fed and IQ scores for adults, but this relationship plateaus at 9 months of being breast fed. The study implies that breastfeeding through 9 months has a positive effect on cognitive development (Mortensen, Michaelsen, Sanders, & Reinisch, 2002).

Infants cannot synthesize LCPUFAs until the age of four and, thus, must receive them partly in the third trimester of gestation and through breast milk. A study found that LCPUFA levels collected through umbilical venous plasma phospholipids was not significantly correlated to IQ at the age of 7. Prenatal supplementation of DHA and ARA during the third trimester does not suffice, and further supplementation through breast milk is required to see the IQ advantage of DHA and ARA (Ghys, Bakker, Hornstra, & van den Hout, 2002). These findings again reiterate how breast milk is essential for development. This adaptation conserves the development required to synthesize LCPUFAs in the womb as it is available through breast feeding.

The literature on the sociocultural factors linked to the breastfeeding and formula feeding is vast. This section provides a brief overview of the literature from 1990-2000 reviewed by Dennis (2002). Women who choose to breastfeed have some common characteristics as being Caucasian, from higher socioeconomic status, well educated, married, older, and non-smokers. However, in developing countries the relationship between socioeconomic status and breastfeeding was found to be inverse. Here, there may be a perception of breastfeeding being old fashioned while formula feeding is a sign of modernity. Other factors, such as a mother's

confidence and shame associated with breastfeeding, influenced her decision to breastfeed or use formula. There is a correlation between the probability of a mother breastfeeding with the number of people in her social network who also breastfeed. Mothers who were employed outside of the house were less likely to breastfeed possibly because of the convenience of formula milk; formula does not require the presence of the mother and can be given to an infant by the father or another caregiver. This finding was particularly related to the maternal leave policies of the country. In addition, the social practices at the hospital, birthing center, or family home—such as placing the newborn with the mother soon after birth, early discharge from the hospital, offering lactation classes, and free packs of formula—influenced the probability of the mother and child breastfeeding. This literature review highlights the ways in which sociocultural history can influence the practices of the mother and infant, and the direct impact this can have on the development in the natural line of the infant (Dennis, 2002).

The example of breastfeeding and formula shows how development in all genetic domains are interlinked. The cultural evolution of formula also highlights the impacts of development in the cultural line on the development in the natural line, as well as the unfortunate fact that the development of cultural tools may not always benefit child development.

4.6 Summary

The purpose of this conceptual thesis was to apply the dialectical relationship between natural and cultural lines across all four genetic domains, with a focus on the neurological underpinnings of development. In phylogenesis, Vygotsky turned to Darwin's theory of natural and sexual selection as an explanatory principle, implying that development of *Homo sapiens* was primarily in the natural line. The Hunting Hypothesis by Ardrey (1970) suggested that the cultural tools of hand held weapons, fire and long distance weapons were the determining factors

of the survival of the *Homo sapiens* species. The Social Brain Hypothesis by Dunbar (1998) suggested that the role of social coalition and tactful deception found only in primate groups created an evolutionary need for an increase in brain size. These suggest that the sociocultural history of our ancestors also led to the development in the natural line. In sociocultural history, the Neurodevelopmental Hypothesis for the Flynn Effect (Blair et al., 2005) and specializations emphasized the dialectical relationships between the natural and cultural lines of development. In ontogenesis, teratogenic effects and familiarity preferences of the foetus demonstrated the influence of development in the cultural line even before birth, in the prenatal environment (Maurer & Maurer, 1988). Studies in developmental neuroscience found that the natural line of development extends much past infancy. The effects of stress on the foetus, infant and adult highlight the connections between the genetic domains of sociocultural history, ontogenesis and microgenesis, as well as the dialectical relationship between natural and cultural lines of development (Gerhardt, 2004). In microgenesis, the interfunctional relationships theorized by Vygotsky have been confirmed through studies in neuroscience. The phenomenon of neuroplasticity, which is reliant on development in both the natural and cultural lines, is suggested as an extension of the explanatory principle for microgenesis. The example of breast milk and formula illustrated how development in all genetic domains are integrated and interlinked, emphasizing the dialectical relationship between nature and culture for cognitive development.

The next chapter connects the conceptual analysis of this conceptual thesis, revisiting Vygotsky's cultural-historical psychology, given the research in the field of neuroscience.

Chapter Five: Implications and Application

The aim of this chapter is to outline the implications of using recent research in the neurosciences to update or amend Vygotsky's genetic method of analysis, and provide an application to research using the genetic method of analysis. The first section delves into the implications of using the research methodology, given the studies and findings from the conceptual analysis described in chapter four. The second section is an application of Vygotsky's genetic method of analysis as a research methodology, using the mathematical development of the concept of abstract number as an example. The chapter concludes with a summary.

5.1 Implications

The purpose of this conceptual thesis was to apply the dialectical relationship Vygotsky explicated only for the genetic domain of ontogenesis across all the genetic domains given research in the field of neuroscience. Although chapter four was divided by four headings into the four genetic domains, it is important to note that this was done purely for analytical purposes. Even the categorization of studies was somewhat arbitrary because the developmental histories overlap and are interrelated. In fact, the very aspect of Vygotsky's genetic method of analysis that makes writing about it complicated is also its strength. The genetic domains are not meant to be viewed as hierarchal or nested, but rather interrelated. In this section, a figure representing Vygotsky's original articulation of the genetic method of analysis and the interconnections between the genetic domains is suggested and compared and contrasted with a figure supported by the conceptual analysis and the amendments to this figure as a result of the studies and findings discussed in chapter four.

5.1.1 Figure of Vygotsky's Genetic Method of Analysis

Little has been written about how the genetic method of analysis should be represented, either by Vygotsky or Luria. In a collection of three essays, Luria and Vygotsky (1992) mention in passing:

> [W]e have sought to comprehend the actual connection between the three paths of development in an entirely different manner. From our approach, this connection means that one developmental process prepares the way dialectically for the next and is transformed into a new mode of development. We do not believe that all three processes may be placed along a single straight line, but we believe that each higher mode of development begins wherever the preceding mode ends, and serves as its continuation in a new direction. This change in direction and in mode of development is [sic] no way precludes the possibility of a link between one process and another, rather it presupposes such a link. (p. iii)

In 1985, Wertsch articulated the genetic domains textually and without a figure. In the same year, Scribner (1985) published a figure to represent the interrelation of developmental histories. The issue of representation is significant given Cole's (2003) caution that developmental histories should not be conflated with contexts, nested or otherwise.

The figure proposed below cannot be validated and is merely suggested as a useful heuristic for thinking through Vygotsky's original conception of the relationship between the genetic domains and the dialectical influences of nature and culture on human development.

Vygotsky's genetic method of analysis can be visualised as seen in Figure 1.1.

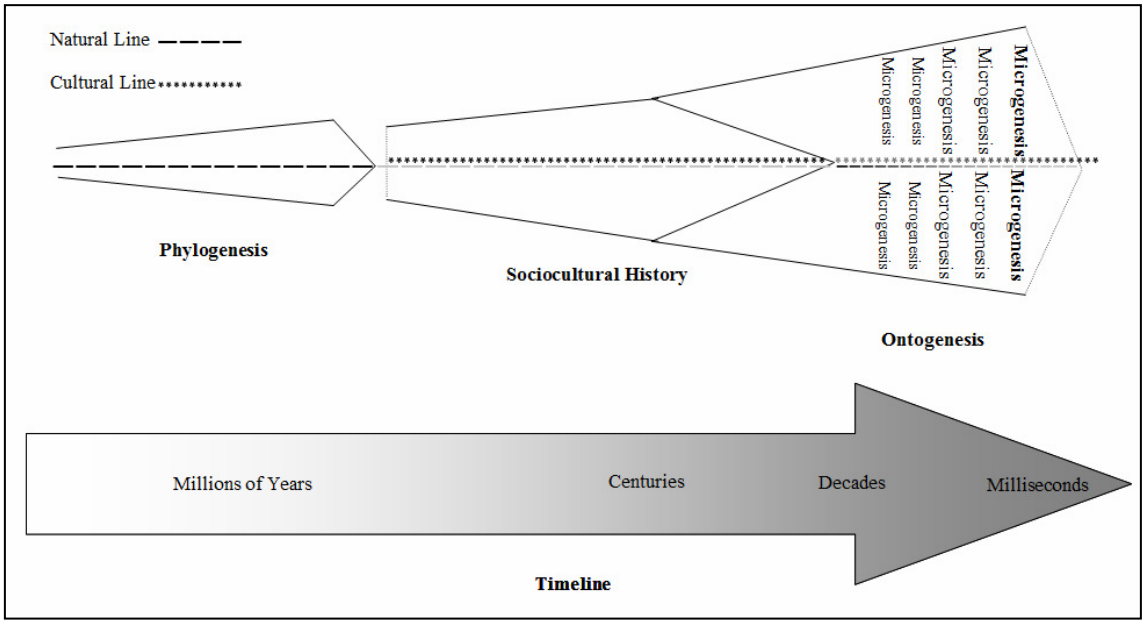

Figure 1.1: **Original figure of Vygotsky's genetic method of analysis**

In this figure, the dashed line represents development in the natural line and the line of asterisks represents development in the cultural line. The figure is explained by taking each quadrilateral apart. After an explanation of each quadrilateral, which represents each genetic domain, the timeline accompanying the figure is explained.

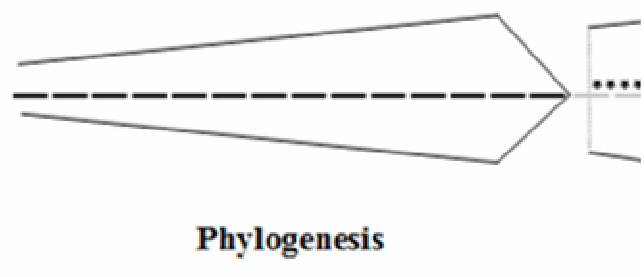

Figure 1.2: **Figure of Vygotsky's genetic method of analysis: Phylogenesis**

The first quadrilateral is the genetic domain of phylogenesis. Development in phylogenesis was considered to be primarily in the natural line through the explanatory principle of natural and sexual selection. The arrow enlarges as it reaches the genetic domain of

sociocultural history since evolution builds upon itself. The permeable boundary between the quadrilaterals representing phylogenesis and sociocultural history represents the Critical Point Theory of the origin of culture. Although it was because of development in phylogenesis that development in sociocultural history is afforded, there remains a boundary between what can be considered development in phylogenesis as opposed to development in sociocultural history.

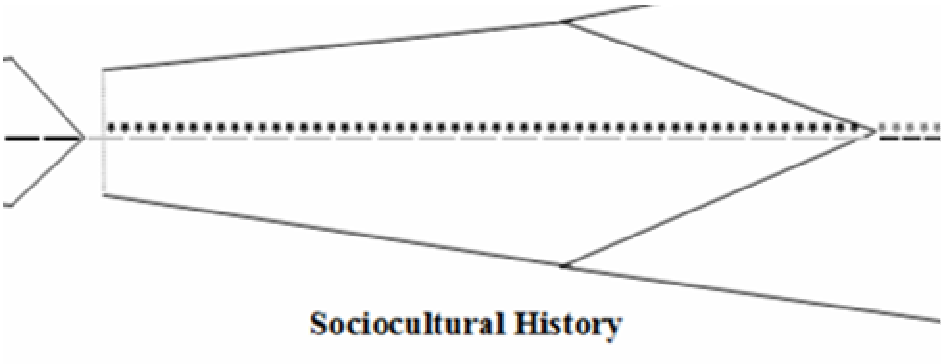

Figure 1.3: **Figure of Vygotsky's genetic method of analysis: Sociocultural History**

In Figure 1.3, the arrow of sociocultural history enlarges since cultural tools and signs also build upon themselves and evolve. The sudden start of the cultural line represents the Critical Point Theory of the origin of culture. The natural line emanating from phylogenesis is not emphasized and is faded. This represents the emphasis Vygotsky placed on the cultural line of development in sociocultural history. It is the cultural line that is the force driving development, however, development in the cultural line is dependant on the constraints and affordances provided by the natural line of development. The basic principle, according to Vygotsky, is that the evolutionary development of biology and anatomy, for example the opposable thumb, shapes the development of cultural tools and signs, for example writing with a pencil. Sociocultural history penetrates into the quadrilateral representing the domain of ontogenesis, since the mother's sociocultural history overlaps with the child's, and the child is born into a society with an established sociocultural history.

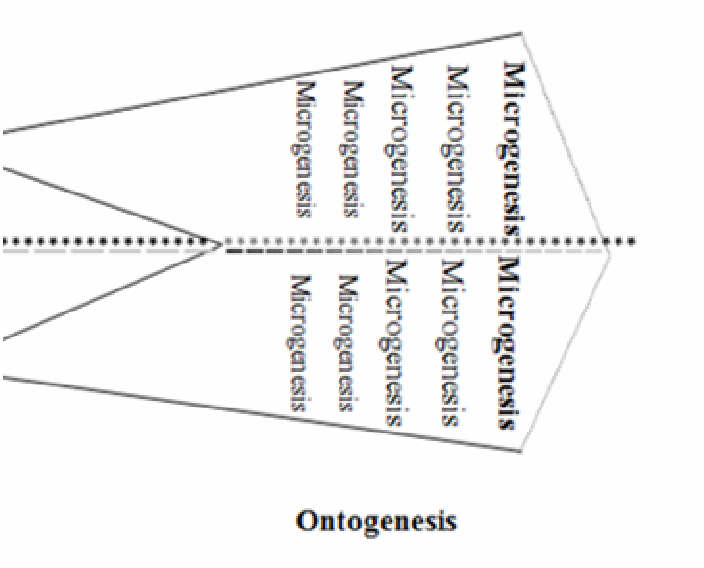

Figure 1.4: **Figure of Vygotsky's genetic method of analysis: Ontogenesis**

The third quadrilateral representing the genetic domain of ontogenesis is an arrow that enlarges, since development over the lifespan builds upon itself, and these developments are the genetic domain of microgenesis that are interfunctionally related. The emphasis begins in the natural line of development and gradually shifts over to the cultural line of development. According to Vygotsky the marker of this shift in development is the child beginning to use speech and language. Going back to the example of the pencil, it is only after the development in the natural line of the child gaining dexterity and motor control of the opposable thumb through experience, that the child can then learn how to use the cultural tool of a pencil. The end of the quadrilateral represents the death of an individual. Although the natural line stops with the death, the individual contributes to the cultural line of development that extends past the individual's death, and so the cultural line continues beyond the boundaries of the quadrilateral representing ontogenesis.

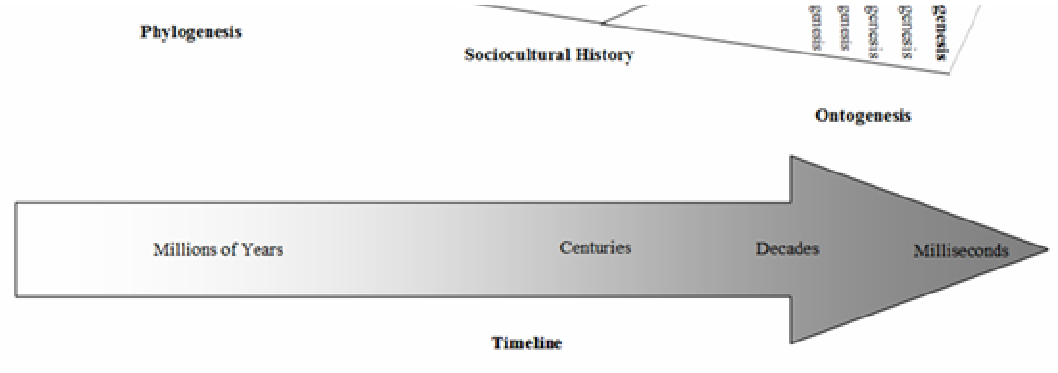

Figure 1.5: **Figure of Vygotsky's genetic method of analysis: Timeline**

Accompanying the figure of Vygotsky's genetic method of analysis is a shaded timeline that represents the units of time, or timescales, correlated with each of the genetic domains. Development in phylogenesis occurred over millions of years, while in ontogenesis and microgenesis, development can be measured in any denomination from decades to milliseconds. With the detailed description of the visual figure of Vygotsky's genetic method of analysis, the complete Figure 1.1 can be viewed to gain a sense of how all the individual parts fit together.

5.1.2 Conceptual Figure of Vygotsky's Genetic Method of Analysis

This conceptual thesis modifies Vygotsky's figure of genetic analysis in two primary ways, as seen in Figure 2.1. First, the natural and cultural lines of development are blended and span across all four genetic domains. Second, the Critical Point Theory of the origin of culture has been edited, changing the figure and the timeline of the modified version.

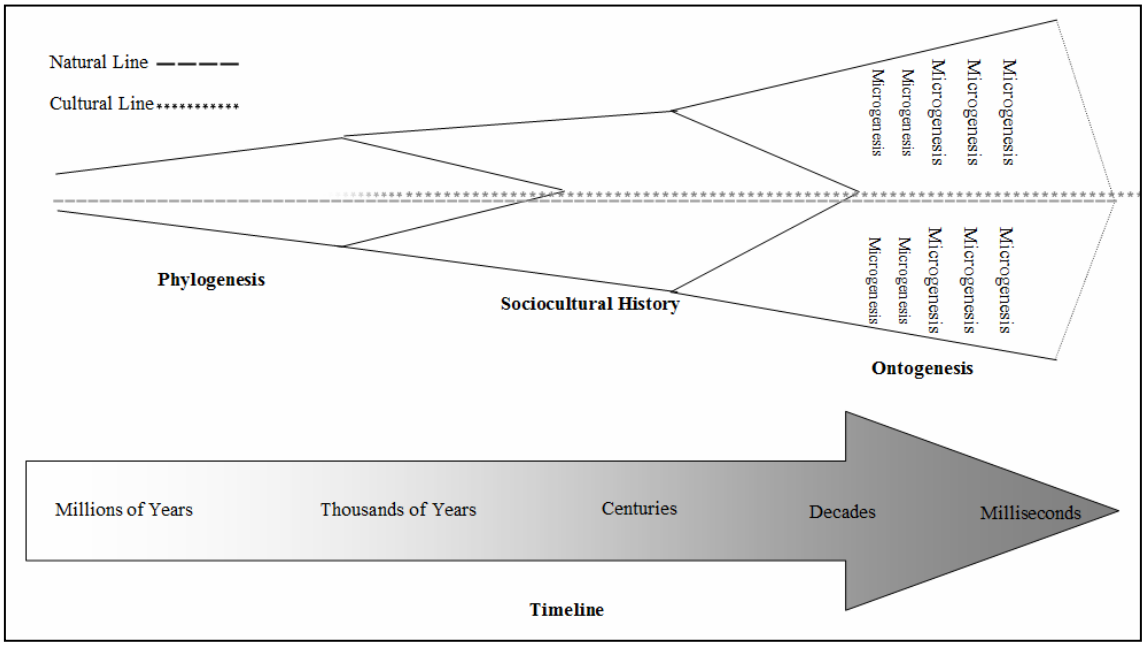

Figure 2.1: **Conceptual figure of Vygotsky's genetic method of analysis**

The dialectical relationships in all the genetic domains have been highlighted in the larger part of this conceptual thesis. This is represented by the lines of natural and cultural development having an equal emphasis across all four genetic domains. Again, the conceptual figure will be taken apart to explain the intricacies of the figure.

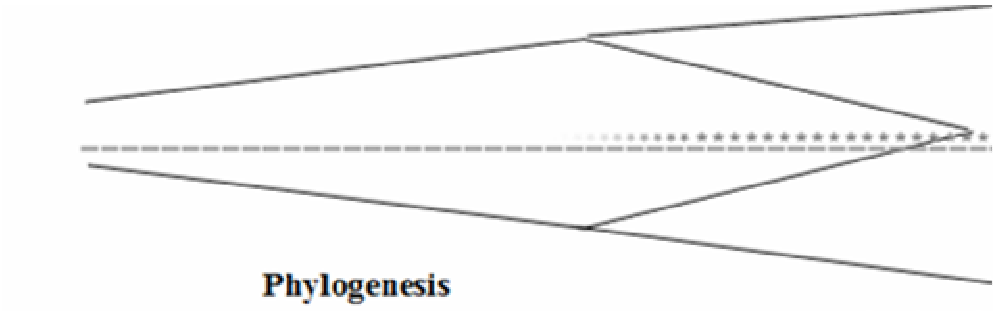

Figure 2.2: **Conceptual figure of Vygotsky's genetic method of analysis: Phylogenesis**

The quadrilateral representing phylogenesis penetrates into the genetic domain of sociocultural history. This represents the critique of the Critical Point Theory of the origin of culture. The faded beginning of the cultural line represents the gradual development of the cultural line, incorporating the Hunting Hypothesis (Ardrey, 1970) and the Social Brain Hypothesis (Dunbar,

1998) that the cultural tools of weapons and fire allowed for the survival of the hominids to the *Homo sapiens* species.

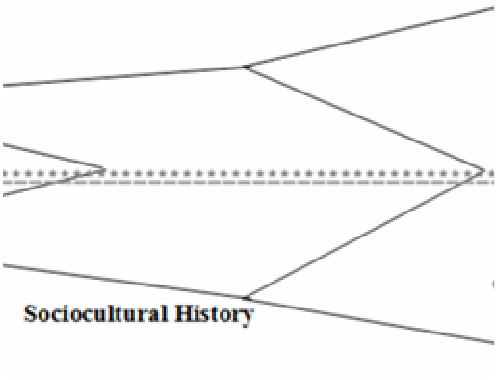

Figure 2.3: **Conceptual figure of Vygotsky's genetic method of analysis: Sociocultural History**

The major change in the quadrilateral representing sociocultural history is that the emphases of the natural and cultural lines are equal. As the Neurodevelopmental Hypothesis of the Flynn Effect (Blair et al., 2005) and the specialized professions demonstrate, development in culture can influence development in nature in relation to sociocultural history. This dialectical relationship between nature and culture removes the emphasis only on the cultural line, and equates both nature and culture, which are dependent on each other, for development.

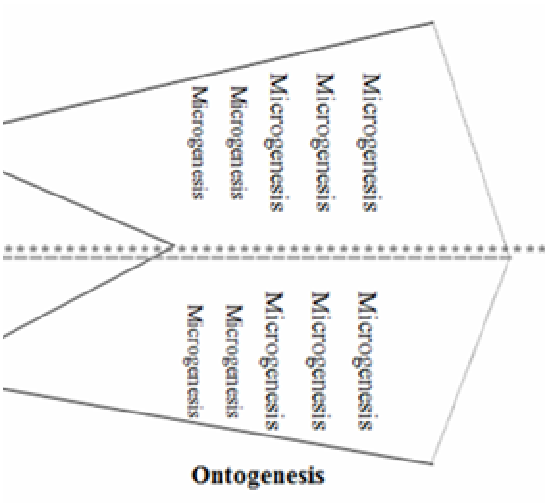

Figure 2.4: **Conceptual figure of Vygotsky's genetic method of analysis: Ontogenesis**

In the genetic domain of ontogenesis, the lack of emphases on both the natural and cultural lines represents the dialectical relationship. In Vygotsky's figure the emphases shifted from the natural line to the cultural line, marked by the child mastering speech and language. However this conceptual thesis noted studies of how development in the cultural line predates even birth, in the prenatal environment and how development in the natural line extends much past infancy.

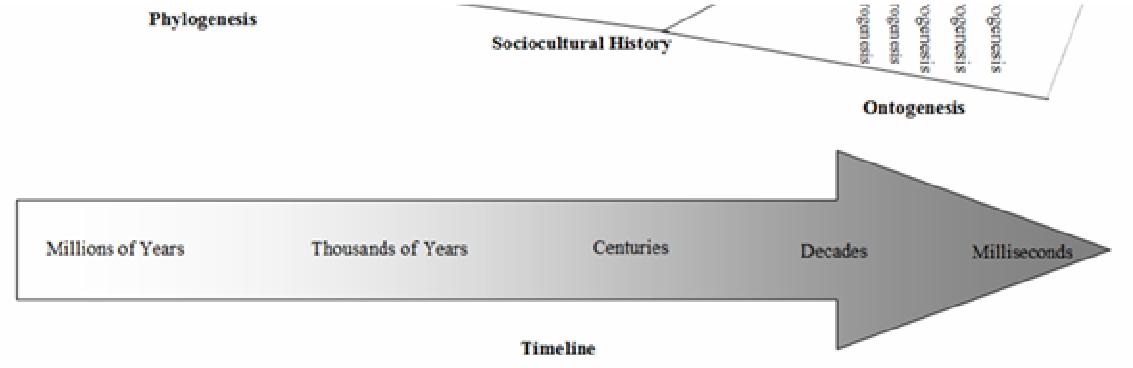

Figure 2.5: **Conceptual figure of Vygotsky's genetic method of analysis: Timeline**

As Geertz (1973) critiqued the Critical Point Theory of the origin of culture, the unit of timeline was not sensitive enough to capture the gradual cultural evolution that occurred over thousands of years, as opposed to millions of years. Therefore the timeline incorporates this, and includes the unit of analysis of thousands of years. The graded shading of the timeline denotes that the units of time are not discrete measures.

Vygotsky's genetic method of analysis provides a research methodology that aims to both describe and explain the development of psychological processes. Although Vygotsky stated that development of psychological processes is a result of both nature and culture, he tended to focus on the cultural line of development. The purpose of this conceptual thesis was to apply the dialectical relationship that Vygotsky explicated only for the genetic domain of ontogenesis across all four domains given the advancements in research and technology since his time. The

conceptual figure of Vygotsky's genetic method of analysis amends his figure in two primary ways. First the natural and cultural lines of development have been equalized. Second, the figure has been modified given that the field of psychology no longer subscribes to the Critical Point Theory of the origin of culture.

5.2 Application

Providing an application of Vygotsky's genetic method of analysis, gives an example of the research methodology. In this section, the focus is on the mathematical development of the concept of abstract number across the four genetic domains.

5.2.1 Development of the Concept of Abstract Number: Phylogenesis

In the genetic domain of phylogenesis, a common research method is to compare and contrast between animals and humans, as well as determine the universality of the psychological process. The founding principle behind these methods is that the psychological processes have an evolutionary precursor if animals other than humans also exhibit them, and that if psychological processes are universal then it must be a result of our evolutionary history, rather than the result of sociocultural history (Dehaene, Dehaene-Lambertz & Cohen, 1998). Another method to analyze whether psychological processes have an evolutionary background is by studying the ability in infants who have minimal exposure to cultural tools and signs.

Animal studies show that there are evolutionary precursors to the development of mathematics. As Dehaene et al. (1998) claimed, "the basics of 'number sense,' the understanding of quantities and their inter-relations, are universal and shared by adult humans, animals and preverbal infants" (p. 355). Animals such as rats, pigeons, raccoons, dolphins, parrots, monkeys and chimpanzees have been shown to differentiate between sets of numbers presented visually, orally and through tactile stimuli. Primates have even been taught to correlate Arabic numerals to

quantities over a period of extended learning (Dehaene et al., 1998). However, the key markers suggesting the phylogenetic history of the mathematical development of the concept of abstract number are the phenomena of number size effect and the number distance effect, which are found in animals, infants and adults. Number size effect is the finding that smaller number sets are easier to differentiate than larger number sets. For example, it is easier to differentiate between the number sets of two and five, than it is to differentiate between number sets of 18 and 21. The number distance effect is the finding that it is easier to differentiate between number sets that have a higher ratio and are farther away from each other on the number line, than number sets that are closer together. For example, it is easier to differentiate between number sets of two and nine, than it is to differentiate between number sets of four and six (Dehaene et al., 1998). As an evolutionary marker, the number distance effect has been negatively associated with the brain areas of the intraparietal sulcus, bilateral prefrontal, and precentral regions in primates and humans (Ansari, 2008).

Geary (1995) stated his evolution-based framework that psychological processes have biologically primary and biologically secondary cognitive abilities, and focused primarily on the development of mathematics ability and the development of the concept of abstract number. Biologically primary cognitive abilities are those that have been evolutionarily selected for, and are ingrained in our genetic and neurobiological makeup. Hence, these must be found universally and/or even have evolutionary precursors in animals other than humans. Biologically primary cognitive abilities are comparable to development in the natural line of cultural-historical psychology. On the other hand, biologically secondary cognitive abilities are a product of cultural tools and signs that shape biologically primary cognitive abilities into the social practices of a particular society. These are comparable to development in the cultural line of

cultural-historical psychology. Biologically secondary cognitive abilities are separate from evolutionary pressures that were responsible for the development of the biologically primary cognitive abilities. However, it is because of the highly specialized biologically primary cognitive abilities, that they can be used for tasks unrelated to their original evolutionary function, much like Vygotsky's third level of psychological development: intelligence (Luria & Vygotsky, 1992). Biologically primary cognitive abilities represent the implicit knowledge that humans then formalize as part of education to share biologically secondary cognitive abilities between people. Development in the biologically secondary cognitive abilities requires copious amounts of practice and interaction with the cultural tools and signs. Since these psychological processes are not based evolutionarily, the motivation for repeated practice depends on the motivation provided by the culture and society (Geary, 1995).

In the case of mathematics and the concept of abstract number, biologically primary cognitive abilities from which biologically secondary cognitive abilities stem from are numerosity, subtizing, and spatial navigation (Geary, 1995). Numerosity is the ability of judging the number of items within a set. The biologically primary cognitive abilities for this psychological process is the visual system being able to distinguish contours and identify objects as separate entities within the visual field. Subtizing is the ability of humans to perceive and distinguish between less than four objects, and is associated with the occipital-parietal cortex. Infants less than a week old are able to distinguish between sets of two or three dots, but not between sets of more numbers of dots (Antell & Keating, 1983), which is also an example of the number size effect. Spatial navigation is found in species that gather food, and is associated with the hippocampus. Spatial navigation is suggested to be the biologically primary cognitive ability of Euclidian geometry that requires spatial navigation (Geary, 1995).

In this section on the development of mathematics, particularly the concept of abstract number, in the genetic domain of phylogenesis, the evolutionary precursor of the number size and distance effects found in animals, and Geary's (1995) evolution based theory was described. According to his theory, biologically primary cognitive abilities of numerosity, subtizing, and spatial navigation are the precursors to the biologically secondary cognitive abilities of counting, and Euclidian geometry.

5.2.2 Development of Mathematics: Sociocultural History

In the genetic domain of sociocultural history, a common research method is to compare and contrast between two human groups. However, Geertz (1973) and Lewontin (1993) noted that biological determinism, which assumes genetic differences between human races, has been challenged, both theoretically and as a tabooed research topic, particularly after Nazism. Added to this, genetics finds that there is more variability between human groups than within (Geary, 1994). Therefore comparing and contrasting psychological processes between human groups has to be done in the utmost sensitive manner, taking into account the sociocultural history of the human groups under consideration. On an added note, when groups are compared statistically on any standardized tests, the means of the groups are determined to be significantly different if they fall outside of *p* values that have been arbitrarily assigned. Given that only the means of the groups are compared, there are many individuals within groups who are higher and lower than the groups they are being compared to, regardless of the group to which they belong. In other words, when comparing Asian and American children, there are many Asian children who perform higher and lower than American children and vice versa. Therefore, the studies comparing group means should not be taken as a determining characteristic of individuals belonging to the group, since there is a high level of variation and distribution within the groups.

Studies by Tobin and colleagues (2009) are especially helpful in this section. In the original study conducted in 1989, Tobin and colleagues collected in depth observational data from preschools in China, Japan and United States and asked key stakeholders of these cultures for their responses to the observations in preschools from their own cultures and other cultures. The researchers revisited the same preschools from 2005-2007 and conducted a comparable study to the original study in 1989, and in addition asked key stakeholders of their responses to the changes they viewed in the observational data from 1989 to 2007 (Tobin, Hsueh, & Karasawa, 2009). The studies by Tobin and colleagues demonstrate how the three cultural contexts are unique, and how the role of education and academic performance needs to be studied from a cultural perspective. This seminal cross-cultural and longitudinal study in the field of education is an example of how sociocultural history can be analyzed comparing both culture and history.

The cultural beliefs about intelligence, academics and education influence social practices. Scores of performance on mathematics tests by different cultural groups have been compared and contrasted by the PISA (Programme for International Student Assessment) international study. It allows for a comparison of education systems worldwide by testing the skills and knowledge of students in participating countries and economies. The results of the PISA concur that Asians score higher than Caucasian Americans (Geary, 1994; Huntsinger, Jose, Liaw & Ching, 1997; Miller, Kelly, & Zhou, 2005). Initially it was thought that Asians had a biological genetic advantage of higher IQ. However, this advantage did not translate across all forms of IQ tests and was only found in mathematical performance (Geary, 1994). The following studies aimed to highlight how the sociocultural history of the societies, rather than biological differences, result in the differences found in mathematical performance. American children

scored higher than Asian children before formal education, but the disparity between American and Asian children began at kindergarten and continued to expand. Therefore, studies showed that it was not genetics, but rather schooling and culture that influenced mathematical performance (Geary, 1994; Miller, Kelly, & Zhou, 2005). What were the social practices that gave Asian children an advantage in mathematical performance? Researchers looked into the family dynamics, and language for cultural differences that may be beneficial for mathematics performance.

In many Asian families, academic expectations for children were higher than in the American families. Asian families believed that academic achievement comes from effort, while American families believed academic achievement comes from effort as well as native ability. Therefore, if there was poor academic achievement the Asian families doubled their efforts to support and teach their children, while American families explained the disparity by suggesting a lack of natural talent (Geary, 1994, Miller, Kelly, & Zhou, 2005). Interestingly, the study did not find a relationship between funding and mathematical performance when comparing countries. In fact, Asian families with small households were found to have an assigned location in the house for the child to study quietly, whereas American families with rooms for each child did not always have a study room or location. These family influences might play a role on the child's performance in mathematics.

Language was an area of interest in looking at possible reasons behind the differential mathematics performance, particularly of the concept of number (Geary, 1994; Miller et al., 2005; Ng & Rao, 2010). The number words differ in English, versus Asian languages. In Chinese for example, numbers are named by the base of ten. So the number "34" is referred to as "three tens and a four." The mathematical concept is inherent in the language and number words,

which is not the same case in English (Geary, 1994; Miller et al., 2005; Ng & Rao, 2010). Therefore, the language structure and the number words may be a cultural difference that influences the mathematical performance of the two groups.

In addition to linguistic operations, visuospatial development is also required for the development of the concept of abstract number (Hanakawa, Honda, Okada, Fukuyama, & Shibasaki, 2003). Mathematical operations are often processed using cultural tools such as pen and paper, calculators, rulers, number lines and computers. A cultural tool that is traditionally used by Japanese and Asian cultures is the abacus, which is a counting frame using beads sliding on rows of sticks. In the initial use of this cultural device, players physically practice with the beads. After mastering the abacus the player can internalize the abacus operations with actual finger movements while representing the beads mentally. A study by Hanakawa and colleagues (2003) has found that expert abacus players use visual strategies for mental mathematical operations. The results from the fMRI study showed that expert abacus players had higher accuracy on numerical processing tasks than non abacus players, and had higher activation of the left posterior superior parietal cortex as well as the brain areas associated with visuospatial reasoning than non abacus players. The researchers suggest that expert abacus players have a higher involvement of visuospatial strategies, while non abacus players have a higher involvement of linguistic strategies (Hanakawa et al., 2003). The influence of the use of the abacus cultural tool is an example of how sociocultural history can influence brain development associated particularly with the psychological processes of the concept of abstract number. It is plausible that cultural tools such as the abacus may have an influence on the difference in mathematical performance between cultural groups. However, this can only remain as a non-

tested hypothesis since empirical data about the use of the abacus cultural tool in the cultural groups being compared is not available.

5.2.3 Development of the Concept of Abstract Number: Ontogenesis

Studies on the development of mathematics across the lifespan concur that there is an innate precursor to mathematical abilities (Geary, 1994). Children as young as a week old are able to distinguish sets that have two dots versus three dots. However, they are not able to distinguish between larger sets of dots. This ability to distinguish small sets of numbers is called subtizing and is thought to be an innate ability (Antell & Keating, 1983). Number is a cultural tool, and an abstract concept that does not describe a particular object, but rather an object in the collective set. Nevertheless, counting and numbers is a natural activity seen across human groups and in children as young as two (Geary, 1994). Early mathematical abilities are divided into four factors, namely; ordinality, one-one representation, cardinality, and order irrelevance. The developments of each of these factors are discussed in this section.

Ordinality is the principle that the numbers are in an order of increasing amounts. Children as young as 18 months have a concept of ordinality up to the amount of four objects. The development of ordinality is noted by children using the terms “more than” or “less than” (Geary, 1994). Ordinality can be the precursor for the mathematical concepts of addition and subtraction. Infants as young as five months old demonstrate the ability to add and subtract small numbers. In an experiment, one or two toys were placed on a pedestal. Then a wall obstructing the toy from the infant’s view was placed. The experimenter either added one more toy, or removed one toy in a manner that was visible to the infant. Then the wall was removed. Infants were not surprised if the number of toys matched the expected number (i.e., if there was one toy, and another was added, the expected number of toys on the pedestal should be two), but were

surprised if the number of toys on the pedestal did not match the expected number following simple addition and subtraction principles (Wynn, 1992).

The one-one correspondence principle in mathematics is that each verbal name represents one object. Children might not be able to count in order, but once they have developed one-one correspondence they will only assign one number label to each object (Geary, 1994). Studies show that children by the age of 3 show a developed concept of the one-one correspondence, if the memory load of counting removed from the task. In the study, a puppet learning to count makes one-one correspondence error by assigning the same number label to two different objects. Children as young as three notice the mistake, suggesting that they understand the one-one correspondence error (Geary, 1994).

Cardinality is the principle that the last number counted represents the number of objects in that set (Geary, 1994). Children three, four, and five years of age have the concept of cardinality, which is not fully developed. Children can resort to the "name the last number" rule when asked "how many." Children will count the set and restate the last number as the answer. To understand whether children have developed the cardinality principle, researchers ask the children to give them three, four or seven objects. If the children have a developed sense of cardinality, they will count out the objects. If they do not, they will arbitrarily grab a handful of objects without counting them (Geary, 1994). Perceptual cues such as a longer row of coins can mislead children into relying on the perceptual cues rather than the cardinality principle. Without perceptual cues, five year olds can rely on the cardinality principle to select the set with more or less number of objects. It is not until seven to eight years of age that children have a matured concept of the cardinality principle, and rely on the cardinality principle regardless of perceptual cues (Geary, 1994).

Order irrelevance is the principle that no matter in which order the objects are counted, the end result is the same. Five year olds do not have the principle of order irrelevance. The belief is that the objects should be counted from right to left, and that skipping objects and returning to count them are not acceptable (Geary, 1994). This finding questions whether children learn counting as rote memory and imitation of behaviour, or whether children understand the concept of counting.

Children by the age of three or four are able to count up to ten and know the number labels for sets of objects up to ten. As mentioned in the sociocultural section on the development of mathematics, the English language does not use base ten words for numbers, creating a higher memory load for English speakers to remember the number words for the teens, and subsequent sets of tens. This issue of language impacts the conceptual understanding of numbers and lags English speaking children in requiring them to memorize the number words before understanding the concept of number (Geary, 1994). Vygotsky noted that in cultures between the prehistoric and pre-industrial periods, numbers were counted in sets. So although there were no words for larger numbers, people could count to high numbers by using sets (i.e., 25 would be five groups of five). This cognitive load has been reduced by the counting system that keeps track of the number of sets (Luria & Vygotsky, 1992).

A method to understand the development of mathematics in children is to ask them to share candy. Children one to two years of age will use the dumping strategy, where handfuls of candy are arbitrarily shared amongst others. Children three years of age will use the one-for-one strategy where they will give one candy to each until the candy is finished. Children four years of age will use the dumping and counting strategy where they will initially use the dumping strategy and then count each person's share to ensure equality. Children five years of age will

use the rule of cardinality, by counting out the sets before dividing the candy but only at seven years of age will children use this method consistently, without being misled by perceptual cues. It is not until nine years of age that children are able to count the number of candies and divide by the number of people and then share the candy accordingly (Geary, 1994). Counting discrete objects does not require estimation unlike length and volume. Children younger than nine years of age divide continuous objects arbitrarily, while nine year olds start to use rulers or tools for measurement. It is not until adolescence that concept of volume is developed (Geary, 1994).

5.2.4 Development of the Concept of Abstract Number: Microgenesis

In the genetic domain of microgenesis, the research methods most commonly used are longitudinal or cross sectional brain imaging studies, coupled with stimulus-response experiments to correlate the development of particular psychological processes and associated brain development.

Brain imaging studies noted that with the development in mathematics ability, brain activation in the frontal lobes, which is associated with concentration and working memory reduces, while activation in the parietal lobe increases (Ansari, Garcia, Lucas, Hamon & Dhital, 2005). In adults, the left intraparietal lobe is associated with mathematical processing. Researchers aim to capture this ontogenic shift and the association with development in mathematics. In the study, fMRI brain images of adults and children performing number processing tasks were compared (Ansari et al., 2005). Number processing is the ability to compare two numbers and judge which is larger. The results showed that children had higher right frontal lobe activation than parietal lobe activation, while the vice versa was true for adults. For adults, the amount of frontal lobe activation was correlated to the number distance effect.

The number distance effect is that the higher the ratio between the numbers, the easier it is to judge which number is higher (Ansari et al., 2005).

To hone in on the ontogenic shift, Cantlon and colleagues (2009) compared fMRI brain scans of children six and seven years of age with that of adults', while they were performing numerical comparison tasks with both symbolic (Arabic numerals) and non-symbolic (number of dots) representations. Concurring with the study by Ansari and colleagues (2005), the results showed that children's frontal brain areas were more activated than the adults'. The authors hypothesised that the frontal regions of the brain were recruited to connect symbolic and non-symbolic representations to the quantity they represented, and when this abstraction was internalized the brain area active during numerical comparisons tasks shifted to the parietal cortex (Cantlon, Libertus, Pinel, Dehaene, Brannon & Pelphrey, 2009). Luria (1973) noted that brain areas associated with higher mental functions are not static, and that over development and training the brain areas become condensed and converted to automatic motor skill. The ontogenic shift from the frontal lobe to the parietal lobes with the development of the concept of abstract number suggests a reduced recruitment of concentration and working memory required for the mathematical task of number processing. With automaticity of the task, the mathematical processing shifts to the parietal regions of the brain.

5.2.5 Application Summary

The application section of this conceptual thesis provided an example of conducting research following Vygotsky's genetic method of analysis. Mathematical development across all four genetic domains was analysed in this example. The evolutionary precursors of subtizing, numerosity, and spatial navigation have been found in animals, infants and adults, as with the number distance and size effects (Geary, 1995). The differential mathematical performance

between cultural groups may be influenced by sociocultural factors, such as language, and cultural tools, such as the abacus. The mathematical development of one-to-one correspondence, ordinality and cardinality, demonstrates the development of the concept of abstract number over the lifespan (Geary, 1994). Finally, neural development suggests a correlation between the development of the concept of abstract number and the ontogenic shift of brain activity from the frontal lobes to the parietal lobes (Ansari, Garcia, Lucas, Hamon & Dhital, 2005). By analyzing the developmental histories of phylogenesis, sociocultural history, ontogenesis and the microgenesis, the psychological processes related to the development of mathematics, focusing on the development of the concept of abstract number may be better understood.

5.3 Summary

Chapter five outlined the conceptual analysis and applications of Vygotsky's genetic method of analysis. The conceptual analysis applied the dialectical relationship between nature and culture across all the genetic domains. An application of this research methodology to the mathematical development of the concept of abstract number provided an example of using Vygotsky's genetic method of analysis for research on psychological processes.

Chapter Six: Conclusion

The last chapter of this conceptual thesis is a concluding chapter that summarizes the entire thesis, and provides the implications, limitations, and the future directions of this thesis. Accordingly, there are four sections in this chapter. The first section is a summary, and consists of an overview of Vygotsky's genetic method of analysis and how the conceptual thesis revisited his cultural-historical psychology given the current research in neuroscience. The second section includes the implications of Vygotsky's genetic method of analysis along with the key points of the conceptual analysis on research methodology on the development of psychological processes. The third section discusses the limitations of this thesis, in particular in relation to literature selection. The final section describes future research directions.

6.1 Summary: Conceptual Thesis

This section contains a brief overview of Vygotsky's genetic method of analysis. After this summary, discussion of the conceptual model of Vygotsky's genetic method of analysis follows.

6.1.1 Vygotsky's Genetic Method of Analysis: Summary

Vygotsky saw the fragmentation between approaches to the study of behaviour and consciousness as a "crises in psychology," that stemmed, in part, from having one explanatory principle across a single hypothesized line of development (Wertsch, 1985). Instead, Vygotsky suggested the genetic method of analysis, based upon an application Marx's historical materialism in social theory to psychological theory, to understand the development of psychological processes (Lee, 1985). To be able to both describe and explain the development of psychological processes unique to humans, the developmental history of evolutionary development (phylogenesis), social practices and cultural tools and signs (sociocultural history),

lifespan development (ontogenesis), and the development of the psychological processes themselves (microgenesis) needs to be analyzed.

Each developmental history, or genetic domain (Wertsch, 1985), has its own explanatory principle. Indeed, the very mode of development changes in each genetic domain. For phylogenesis, Vygotsky suggested Darwin's theory of natural and sexual selection as the explanatory principle (Wertsch, 1985). For sociocultural history, Vygotsky suggested the explanatory principle of the decontextualization of mediational means. Decontextualization of mediational means enables a uniquely human ability to use and think with abstractions, or mental representations of objects and situations that are not concretely present in the immediate physical environment. It is through the decontextualization of mediational means that humans are able to share cultural tools and signs across generations and with each other (Wertsch, 1985). For ontogenesis, Vygotsky explicated the dialectical relationship between the cultural and natural lines as an explanatory principle. Even so, in his own research, Vygotsky tended to limit discussions of the natural line up through the point at which a child mastered language and deemphasized the natural line beyond this point. As the child internalized speech and language over time, the influence of the natural line was considerably reduced and culture as the mode of development took precedence. The subsequent development occurred most significantly along the cultural line. Therefore the development in the natural line, passed down by phylogenesis provided the affordances and constraints for sociocultural history and development in the cultural line to occur (Wertsch, 1985). For microgenesis, Wertsch (1985) suggested that Vygotsky implied interfunctional relationships between psychological processes as a potential explanatory principle. Vygotsky (1991a), and his student Luria (1973), extended the research in the genetic domain of microgenesis emphasizing localization and plasticity.

These four genetic domains are not meant to be nested contexts, but dialectically interrelated. Even the division of development into the natural line and cultural line was done only for analytic purposes; actual development is intertwined and it may not be possible to differentiate between development in the natural or cultural line cleanly. The concept of unity (Vygotsky, 1994), underlying both the work of Vygotsky and Marx, propels the conceptual work across disciplines in this thesis: implicit in the dialectical relationships across domains is the unity of nature and culture though one tends to be emphasized at given historical moments over the other.

Vygotsky suggested theories for the interrelationships between the genetic domains. For example, the explanatory principle for the genetic domain of microgenesis is that of interfunctional relationships: the development of psychological processes are interdependent over the course of microgenesis and ontogenesis, and a change in one necessitates a change in others (Wertsch, 1985). Likewise, according to Vygotsky, microgenetic development is facilitated by social interactions that result from sociocultural history. Vygotsky (1978) theorized the concept of the zone of proximal development: when children learn the use of cultural tools and signs by interacting with these mediational means in advance of their actual development in interactions with more experienced others. The zone of proximal development is the difference, or developmental potential, between the use of cultural mediational means an individual can use without assistance, and what an individual can use with assistance from an adult or more capable peer. Vygotsky applies the term internalization for the process of the child learning to use cultural mediational means for their own purpose. Internalization occurs over the lifespan, and enables the influence and transformation of sociocultural history during ontogenesis (Wertsch, 1985).

In regard to the interrelations between phylogenesis and other domains, the perspective from the literature is that brain activity is metabolically expensive, and all psychological processes (microgenesis) must have had an evolutionary advantage (phylogenesis) for them to exist in contemporary humans. With natural and sexual selection, organisms that have characteristics adapted to the environment survive and are more likely to reproduce. Through sexual selection, the genes of the organism are passed on to the next generation. Therefore, the genes in the natural line are inherited, and coupled with cultural factors, these genes unfold providing biological constrains and affordances for the development in ontogenesis to occur. In regard to the interrelationship between phylogenesis and sociocultural history, the Critical Point Theory was in vogue during Vygotsky's time (Wertsch, 1985). It was suggested that a critical, albeit small evolutionary change allowed *Homo sapiens* the use of language, which led to a surge of development in the cultural line. Therefore, the Critical Point Theory bridges and isolates the genetic domain of phylogenesis from sociocultural history.

6.1.2 Conceptual Analysis: Summary

Vygotsky applied aspects of Marx's historical materialism to the field of psychology. To study the development of psychological processes, researchers needed to understand the individual in relation to society because socially organized forms of labour differentiate human consciousness from other animals (Lee, 1985). Human consciousness changes according to changes in socially organized forms of labour. Therefore, research on human consciousness needs to be continuously updated in accordance to current social and historical forms (Lee, 1985). This is precisely what this conceptual thesis attempts to achieve. In this conceptual thesis, Vygotsky's genetic method of analysis, which is a research methodology to explain and describe psychological processes, is revisited given a selection of literature reflecting the new

technological means utilized in research. New technology, theories, and research since Vygotsky's time were used to reflect back on his ideas and update them in the manner that both he and Marx argued was expected of the larger project of human culture. The dialectical relationship that Vygotsky applied to the genetic domain of ontogenesis, the existence of both natural and cultural lines with the gradual supplanting of nature by culture, was applied across all the four genetic domains in this conceptual thesis.

In phylogenesis, the Critical Point Theory which was in vogue during Vygotsky's time was critiqued by Geertz (1973) based on three factors: 1) comparative studies between the mental abilities of apes and humans, 2) evolution seen in the timescale of speciation, 3) an untested theory of psychic unity amongst all human groups. Geertz's critiques to these factors were: 1) comparative studies should be between the closest relatives of *Homo sapiens*, and not simply the closest living relatives of *Homo sapiens*, since the phylogenetic split occurred in the Pliocene era and there has been much evolution since then; 2) evolution seen in the timescale of speciation overlooks the gradual cultural evolution that occurred in our ancestors, and; 3) the taboo of biological determinism holds back researchers from studying differences in mental functions between human groups. Studies that attempt to find human universals, on the contrary find differences between human groups, rather than similarities.

The Critical Point Theory has been replaced by the Hunting Hypothesis by Ardrey (1970) and the Social Brain Hypothesis by Dunbar (1998). The Hunting Hypothesis suggested that the survival of *Homo sapiens* was because of the cultural tools and signs. Weapons allowed the Homo genus to survive the migration to the savannah and compete with expert hunters such as the leopards. Controlled access of fire allowed the Homo genus to migrate to cooler geographic regions, survive the Ice Age and begin the culture of cooking. Long distance weapons were the

advantage *Homo sapiens* had over Neanderthals, since it enabled *Homo sapiens* to hunt large animals (Ardrey, 1970). The Social Brain hypothesis suggested that the increase in brain size is related to the number of social interactions and relationships. This hypothesis is supported by the fact that the group sizes of primates and humans had a positive relationship with brain size (Dunbar, 1998). However, an ongoing question is whether increased brain size allowed for the evolution of culturally mediated tools and social relationships, or whether the evolution of culturally mediated tools and social relationships lead to the enlargement of brain size. While some would pursue this question, from a Vygotskian perspective nature and culture are mutual constituents and, thus, the best way of talking about the relationship may be as a simultaneous one.

In sociocultural history, cultural tools and signs mediate development in the natural line. The Neurodevelopmental Hypothesis of the Flynn Effect (Blair et al., 2005) suggested that universal formal schooling and the consecutive downshift of the mathematics curriculum has led to the Flynn Effect and the related increase of the prefrontal cortex in American societies. Specialized professionals who master the use of particular cultural tools and sign—such as spatial maps and musical notation—have been found to have larger brain areas associated with that particular function. These are vivid examples of how cultural tools and signs passed through sociocultural history can influence development in the natural line. Again, the caveat remains whether it is the cultural tools and signs that lead to brain development, or whether brain development leads to the choice of profession and mastery of cultural tools and signs. This highlights the dialectical relationship between the natural and cultural lines of development; one that cannot be easily differentiated.

The explanatory principle that Vygotsky suggested for the genetic domain of ontogenesis was the dialectical relationship between natural and cultural lines. Even so, Vygotsky implied that the development in the natural line precedes development in the cultural line, and that they both develop in relative isolation. Therefore, for the genetic domain of ontogenesis, the focus of the conceptual thesis was two fold: 1) to highlight research showing that development in the cultural line predates infancy and; 2) to highlight research showing that development in the natural line occurs past infancy. New research methods and technology, such as brain imaging, foetal monitoring and amniocentesis have advanced research in human development. Studies on taste and sound in the prenatal environment showed that a preference for the familiar begins in the womb (Maurer & Maurer, 1988), and so cultural development not only predates infancy, but birth itself! The cultural practices of the mother, such as smoking and drinking, have a direct impact on the natural development of the foetus. On the other hand, development in the natural line, particularly that of brain development has been found in adults well into their fourth decade of life (Courchesne et al., 2000). These studies, which were possible because of the technological advancements since Vygotsky's time, show that development in the cultural line predates infancy, and that development in the natural line occurs much past infancy.

The explanatory principle for the genetic domain of microgenesis that Vygotsky intended is unclear, though interfunctional relationships between psychological processes seems to be a potential candidate. Luria's (1973) neuroscientific research focused on the domain of microgenesis, and more specifically on localization of brain functions and plasticity in the event of brain injury. Studies in neuroscience confirm that interfunctional relationships between psychological processes is the explanatory principle for the genetic domain of microgenesis, and extend this to the principle of neuroplasticity. Neuroplasticity is the theory that the input of

external stimuli and experiences strengthens the associated brain areas, therefore marrying the decontextualization of mediational means with the biological development of the brain. The central role of interfunctional relationships was particularly highlighted in the disorder of conduction aphasia, where it is the disruption in the interfunctional relationships between the Broca's area and the Wernicke's area that results in conduction aphasia (Damasio & Damasio, 1980). Vygotsky only had access to post mortem studies, where he compared brains of deceased patients and the compromised psychological processes associated with the brain lesions. With the advancement in brain imaging studies, it is now possible to study brain activity *in vivo* while the participants perform various behaviours. This development has a large impact on the research particularly in microgenesis, leading to the new field of neuroscience.

6.2 Research Methodology

Vygotsky's genetic method of analysis provides researchers with a methodology that attempts to explain and describe psychological processes. In the field of neuroscience, the drive is for the localization of function, where brain areas are associated with particular psychological processes, following the scientific method (Johnson, 2001). These studies are valuable in filling the gaps, with the advancement of technology, particularly in the genetic domain of microgenesis. In the scientific method, the aim of the research methodology is to isolate the object under study in order to obtain data that is not influenced by other factors. In a true experiment, the researcher manipulates an independent variable and observes the effects of the manipulation on the dependent variable. Extrinsic factors that may affect the dependent variable are controlled. True experimental method is considered the ideal in obtaining evidence. However, a limitation of the true experimental method is the lack of generalizability to the social context (Crotty, 1998).

The stimulus response framework of the experimental method was popularized by Behaviourism, which Wundt suggested as adequate to study the elementary psychophysiological characteristics, but not the higher psychological functions (Vygotsky, 1978). Therefore, a new methodology to study human psychology was required. Following Marx's philosophical tenets led to the hypothesis by Vygotsky and his colleagues that the history of development, the historical change, mode, and process of development, was more important if research sought to be able to explain the development of psychological processes, as well as describe them. It is important that researchers recognize that the psychological processes come from a long social and historical development. As Vygotsky stated, it is only when the origin and history of psychological processes is analyzed that psychology can go beyond describing, and explain the science (Wertsch, 1985). Vygotsky's genetic method of analysis provides a research methodology in a codified manner that organizes the historical development into four developmental histories.

Vygotsky's genetic method of analysis, and the modifications suggested in this conceptual thesis, provides researchers with a methodology to gain an historical view of the development of psychological processes. Research questions arise from each genetic domain to understand the developmental history of the psychological processes. For any psychological processes to develop or exist, we might ask, what was the evolutionary advantage the psychological processes provided in the developmental history of *Homo sapiens*? The brain is metabolically expensive and any psychological process places a load on the brain. Given the cost and benefit analysis, there had to be an evolutionary advantage of psychological processes to still exist in the modern human. Researchers need to analyze possible evolutionary advantages of psychological processes in the genetic domain of phylogenesis. Researchers then need to

question, “How does the sociocultural history of the society an individual is born into, affect and influence the development of psychological processes?, and then analyze the development of psychological processes across the lifespan, studying both the natural and cultural lines of development.

This conceptual thesis suggests neuroplasticity as an extension of the explanatory principle of interfunctional relationships. The basic principle is that each psychological process develops with the individual’s interaction and experience with the cultural tools and signs. The researchers need to analyze how this development occurs in the genetic domain of microgenesis. When researchers analyze the historical development across all four genetic domains in Vygotsky’s genetic method of analysis, the psychological processes under study are not only described but also explained. Such research methodology allows for a comprehensive and organized overview of the development of the psychological processes under study.

Although Vygotsky implied that psychological processes develop from both the natural and cultural lines, he focused primarily on the development in the cultural line (Cole, 2007). In this conceptual thesis, the dialectical relationships between the natural and cultural lines of development across all the genetic domains have been highlighted. This focus on dialectical relationship adds another layer of complexity to Vygotsky’s genetic method of analysis, providing a research methodology that incorporates the theoretical concept that development of psychological processes is in both the natural and cultural line.

Interdisciplinary research is lauded and in recent times there has been a large surge for interdisciplinary research. As Wertsch (1991) stated, “we need to reformulate the questions we ask so that disciplinary and sub disciplinary integration will be a natural, or even necessary

outcome" (p. 4). Research conducted using Vygotsky's genetic method of analysis calls for interdisciplinarity.

6.3 Limitations

The limitations of this conceptual thesis are at least two fold: 1) the researcher's selection of the literature and texts and; 2) the researcher's interpretation of the literature and texts.

The selection of literature and texts to represent each genetic domain and discipline was reduced to literature that was directly useful in making arguments for or against the genetic method. The studies included in this conceptual thesis were limited to the breadth of literature exposure of the researcher, and supervisory committee. As noted, the researcher was exposed to the fields of anthropology, sociology, psychology and neuroscience through her undergraduate degree. This exposure was crucial to the culmination of this conceptual thesis. However, a level of saturation was not reached in the literature review as it would have been beyond the scope of this Master's thesis. Studies that were sufficient to provide examples of the dialectical relationship between the natural and cultural lines of development in each of the genetic domains were used. For example, I was not able to survey all of cultural anthropology for my discussion of phylogenesis, and instead focused on literature that could be used to elaborate or amend Vygotsky's theory, in particular in relation to work by Wertsch (1985) that provided an initial critique. I also did not survey all of archaeology or evolutionary theory, although I was initially hoping to do so. This thesis was, by necessity, severely reduced by the scope of the project.

The focus of this conceptual thesis was the neurodevelopmental underpinnings of development. This meant that studies demonstrating a dialectical relationship between the natural and cultural lines of development, in other forms, such as genetics, were not included. The focus on the neurodevelopmental underpinnings of development helped to narrow the research

included in this conceptual thesis, but by no means suggests that it is the only manner in which the dialectical relationship between natural and cultural lines across all genetic domains can be demonstrated.

In addition, a limitation of this thesis surfaced in relation to my interpretation of literature and texts. Vygotsky was a Soviet scholar, and his texts were in Russian. It is only in the past 25 years (Cole, 2003) that Vygotsky's works have come into vogue. They are currently being translated into English, some as recently as Vygotsky (2011), and there are also competing English interpretations (*Thought and language* (1986) and *Thinking and speech* (1987)). Therefore, even though the theory and research dates from 1924-1934, during Vygotsky's career peak, the texts have only been recently available to non-Russian readers. The heavy reliance on translated texts disadvantages the reader and requires a dependence on other's translations. Taking the social constructionist approach, the filter of the translator influences the text, so the reader does not gain a direct access to Vygotsky's ideas. In a similar sense, as the researcher, my own filters have influenced what is written here, including the selection of literature, the constructing of arguments, and what the literature has been taken to mean.

6.4 Future Directions for Research

The figures of Vygotsky's genetic method of analysis and the subsequent modified figure provide a visual representation of the whole of the research methodology. This figure provides a framework of research methodology that incorporates both nature and culture across all the four developmental histories. Such a framework has the potential to enable consistency in the research methodology, and literature reviews of future research on the development of psychological processes.

The figure of the genetic method of analysis demonstrates Vygotsky's theory in a succinct way, and provides a visual representation of the research methodology. To the best of our knowledge, a figure representing the whole of the genetic method was only proposed by Scribner (1985), with a hierarchal representation of the genetic domains, and a related figure can be found in Cole (1996). The figures composed in this conceptual thesis integrate texts from Vygotsky (1997b), Vygotsky and Luria (1992), Cole (2007), and Wertsch (1985) and attempt to include all the complexities of the genetic model of analysis in a visual format.

Having such a succinct figure of the whole of the genetic method of analysis provides researchers with a framework to follow for research on psychological processes. Many articles implicitly apply the genetic method of analysis although they frequently do not define it or show the data used to represent its complex components and interactions. The figure from this conceptual thesis may be used as a tool to organize future cultural-historical research, potentially enabling both dialogue about the problem of representation, as well as improving consistency across research.

Current research reconciles the nature-nurture debate, something Vygotsky foreshowed long ago. Saying that *both nature and culture* are key influences in development, and in fact cannot be separated, results in questions around how to apply this idea and how to study psychological processes as well. The dialectic relationship between nature and culture across all four genetic domains provides a framework for researchers to incorporate both lines of development. The drawback and the strength of research conducted under such a manner is the requirement for interdisciplinary research that may call for larger research teams with specialists from different disciplines. Research from disciplines such as evolutionary psychology, anthropology, archaeology, psychology, sociology and neuroscience all collaborating and

focusing on the development of particular psychological processes may allow researchers to both describe and explain human psychological processes. The figure from this conceptual thesis may provide a framework for such collaboration, following the genetic method of analysis.

As Vygotsky (1997c) stated with regard to the developmental history of research itself, "We are dialecticians. We do not at all think that the developmental path of science follows a straight line, and if it has zigzags, returns and loops we understand their historical significance and consider them to be necessary links in our chain, inevitable stages of our path …" (p. 336). This conceptual thesis offers a small step in the developmental path of science and advances a research framework that potentially enables consistency in future cultural-historical research on psychological processes.

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Appendices

Appendix I: Key Concepts

Natural Line: The natural line refers to development in physiology and is primarily determined by biology.

Cultural Line: The cultural line refers to development in the social realm, and is primarily determined by the mediation and internalization of cultural tools and signs.

Dialectical Relationship: A dialectical relationship is a bidirectional cause and effect relationship, wherein one element presupposes the other. For example, in economics the supply of a commodity is reliant on the demand, which in turn is dependent on the supply. A change in either factor influences the other. In this thesis, the dialectical relationship between nature and culture is highlighted. For example, in the development of language, the biological development of motor control of the tongue is required along with the social exposure and interaction with language.

Tools: According to Vygotsky, tools are objects in the environment that humans manipulate in order to master nature beyond the physiological allowances of humans. Tools are technical tools that are external to human consciousness, and tend to be material. The skill of tool manufacturing is shared from person to person, and so it is culturally mediated (Wertsch, 1985). For example, humans manipulate a rod of wood to create arrows, which allow humans to hunt animals at a distance.

Signs: According to Vygotsky, signs are objects that can be external or internal that humans manipulate, in order to influence the behaviour of others and master one's own behaviour, and tend to be ideal. Once internalized, signs are psychological tools that form the

foundation of human consciousness. The use of signs and their psychological representation is always culturally mediated. For example, writing a list and then memorizing the list is a way humans use signs to remember items on the list with the aid of language, pen and paper, which are all culturally mediated. Signs enable meaning to be constructed by the individual to control one's own behaviour (Wertsch, 1985).

Culturally Mediated Tools: Used to infer both tools and signs. This is in an effort to reduce the complex task of differentiating between tools and signs, as it is not the focus of this conceptual thesis.

Semiotic Mediation: Semiotic mediation is the concept that the experiences of objects in nature and culture are not direct, but rather mediated by meaning constructed by culture. For example a clock tells time, while for a dog the same clock is nothing more than a circular object with moving parts. According to Vygotsky, language is the primary sign system that transforms development from the natural line to the cultural line. Language, in particular speech, is uniquely human.

General Genetic Law of Cultural Development: Vygotsky's law of development is that any function of development appears twice, on two planes. First it appears in the social, inter-psychological plane, where the child observes the function, and over interaction with the function internalizes it to the second intra-psychological plane (Wertsch, 1991).

Genetic Method: Explains the development of psychological processes, rather than merely describing it. The phenotype describes the outwardly expressed characteristics, whereas the genotype explains the characteristic. Vygotsky proposed the genetic method of analysis, consisting of four developmental histories to explain the development of human psychological processes: phylogenesis, sociocultural history, ontogenesis, and microgenesis.

Phylogenesis: Phylogenesis is the developmental history of the human species in the genetic method of analysis proposed by Vygotsky. The evolutionary characteristics that distinguish humans from other animals are highlighted.

Sociocultural History: Sociocultural history is the developmental history of culturally mediated tools and social practices that are shared from one generation to the next. Sociocultural history needs to be analyzed both historically and geographically, since the developmental history of a culture is dynamic and not universal.

Ontogenesis: Ontogenesis is the developmental history through the lifespan of an individual: birth to death.

Microgenesis: Microgenesis is the developmental history of particular psychological processes. The development of memory is an example, from natural memory to mediated memory. This includes the changes that occur in milliseconds through the changes that occur over the lifespan. According to Vygotsky, psychological processes are interfunctionally related and cannot be studied in isolation (Wertsch, 1985).

Explanatory Principle: According to Vygotsky, each developmental history requires a different type of explanatory principle since the development in each of these genetic domains is different. For example, in phylogenesis the development is that of the human species whereas in sociocultural history the development is that of cultures and culturally mediated tools, therefore different explanatory principles are required to explain each of these genetic domains.

Natural and Sexual Selection: Darwin's theory of natural selection and sexual selection is that the organisms with characteristics most suitable for the environment will survive and pass on their genes to the next generation. In this manner, the suitable characteristics become dominant, while the unsuitable characteristics become extinct since the organisms perish before being able

to reproduce and pass on the genes to the next generation. For example, during the Industrial Revolution, peppered moths that were dark in color were camouflaged given their complementary color with soot covered buildings. Therefore, they were less likely to become prey. Light coloured peppered moths contrasted with the dark background, and were likely eaten before they reached reproductive age. In this manner, peppered moths with dark coloring passed on their genes to the next generation, while peppered moths with light coloring became extinct. Vygotsky uses natural selection and sexual selection as the explanatory principle for the development of the human species in the genetic domain of phylogenesis.

Decontextualization of Mediational Means: The decontextualization of mediational means enables human beings to have the ability to represent objects and experiences without requiring a concrete object or context through the use of culturally mediated tools. For example, when learning word meaning a child may point to an object and the caregiver will repeat the word “ball.” After the child has understood the meaning of the word “ball,” the child no longer needs a concrete example of a ball to know what the word “ball” refers to, and is able to have a mental representation of a ball with just the word. Vygotsky uses decontextualization of mediational means as the explanatory principle in the genetic domain of sociocultural history.

Internalization: Internalization is a process that results in a culturally mediated tool being utilized for the individual's own means and not simply as an imitation of previously observed behaviour. It is a process that moves the ideal aspect of a cultural tool from an external or social level, to the internal or individual level, of the individual. As the individual observes another utilizing a cultural tool, she begins to interact with the culturally mediated tool and learns how to use the culturally mediated tool (Vygotsky, 1978; Wertsch, 1985). Vygotsky used the example of how an infant randomly moving her or his arms, transforms this movement into grasping and

later into pointing, because the caregiver imposes meaning on the random gesture, which the infant then internalizes.

Zone of Proximal Development: The zone of proximal development is the difference, or developmental potential, between what an individual can achieve without assistance, and what an individual can achieve with assistance from an adult or more capable peer. For example, when a child is faltering on a question, adults may offer guidance through leading questions such as, “And what happens after that?” This guidance provides the child with cues to be able to answer the question.

Appendix II: Significant Inventions of Mediational Means

On a slight deviation from the focus on neurodevelopmental underpinnings of development, this section highlights some of the key inventions of mediational means and how they relate to Vygotsky's decontextualization of mediational means. These culturally mediated tools have allowed humans to control nature, and overcome the constraints of their physical environment. The tools are listed in order of invention and in the categories of transportation, dissemination of information, medical inventions, and miscellaneous (Haven, 2007).

Transportation

Inventions of transportation have allowed humans to cover distances, and thus have resulted in the globalization of the world. These mediational means have facilitated development of higher psychological functions of business and travel, expanding the reach of an individual to the globe and beyond.

- Wheel
- Roads
- Magnetic compass
- Railroad
- Automobile
- Airplane
- Space shuttle

Dissemination of Information

Language plays an important role in the decontextualization of mediational means as it is the medium through which cultural tools and signs are shared between individuals. Inventions of mediational means that facilitate the dissemination of information are vital in the development of sociocultural history. These technological advancements have reduced the time required to share

information, while increasing the audience and geography to which this information can be spread.

- Paper
- Printing press
- Telephone
- Radio
- Television
- Computer
- World Wide Web
- Social media

Medical Inventions

Medical inventions are interesting mediational means that allow humans to master nature almost to the extent of mastering the process of natural selection! These medical inventions have not only intervened with development in the natural line of humans, but have extended to veterinary fields as well.

- Eyeglasses
- Thermometer
- Vaccinations
- Brain imaging
- Artificial heart
- Cloning

Miscellaneous

The cultural tools included in this section are those that are particularly abstract and an example of the uniquely human ability for the decontextualization of mediational means. The number zero, and the concept of time recorded to the nanosecond, are abstract concepts that do not visibly exist in nature and, yet, are vital for the social organization of societies that utilise them. Photography and other recording devices have allowed humans to reexperience the present moment, and are external signs that aid memory. The electric light bulb has reduced our reliance on the sun to providing light, and allows our vision to work throughout the day and in spaces where natural light is not easily available.

As Vygotsky's cultural-historical theory stated, mediational means are the foundation of development of higher psychological functions. As tools and signs evolve, so does human consciousness given the new information available. Therefore, the study of human consciousness needs to be revisited according to the sociocultural history of that particular time and society. This thesis attempts to do the same, given research since Vygotsky's time, potentially supplementing his cultural-historical psychology.