INVENTIVE THOUGHT IN ENDOGENOUS ECONOMIC DEVELOPMENT: AN EMPIRICAL COMPARISON OF DARWINIAN AND LAMARCKIAN APPROACHES

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Submitted in partial fulfillment of requirement for the degree
DOCTOR OF PHILOSOPHY IN URBAN STUDIES AND PUBLIC AFFAIRS
at the
CLEVELAND STATE UNIVERSITY
October, 2011

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DEDICATION

For my daughter Minhae Kim, late-wife Yusun Lee, father Duha Kim, and mother Chunja Oh

ACKOWLEDGEMENT

First of all, I would like to appreciate my dissertation committee. Dr. William M. Bowen has been a mentor for the whole project and for my entire course of study. He has been inspired and guided this dissertation. Dr. Camilla Stivers encouraged me to do qualitative study and changed my view of research in social science. Dr. Chieh-Chen Bowen helped me to develop survey items and taught me about data and analysis while Dr. Roger Stough assured the importance of this project and its implications for economic development. Without their help this project could not be finished. They intellectually and emotionally supported me from start to end. I was attempted to quit million times and they were my motivation in finishing this project.

I also thank other faculty members, Drs. Edward Hill, Larry Ledebur, Ziona Austrain, Iryna Lendel, Helen Liggett and Sylvester Murray. They were the foundation of my knowledge in economic development. Special thanks to Dr. Sugie Lee, Chang-Sik Song, Misun Park, Eugene Choi, Dayoung Ahn, and Sunjoo Park. They helped me out when I was in difficulty and sorrow. Moreover, I appreciate the staff at the Levin College who encouraged me to complete this project, especially Suzanne Pokorny, Priscilla L. Lewis, and Olinda Paschal.

감사의 글

먼저 물심양면으로 학위를 마치는데 도움을 주신 부모님과 형님, 형수님들께 감사를 드립니다. 마지막 마무리 단계에서 많이 힘들었을때 끝까지 믿어주시고 지원해 주셔서 이 부족한 논문이 나올 수 있었습니다. 특별히 민혜를 2년 동안 돌봐주신 네째 형수님께 감사하다는 말을 지면을 통해 드립니다. 무엇보다 많이 놀아주지 못한 민혜, 먼저 하늘로 간 이유선 집사와 가족분들에게 고마움을 전합니다. 그리고 오 은혜 양께 감사의 마음을 전합니다.

조언과 배려를 아끼지 않으신 윤 대기 선생님, 하 성규 교수님, 허 재완 교수님, 전 명진 교수님, 문 태훈 교수님, 이 수기 교수님, 원 광희 박사님께 감사를 드립니다. 포기하고 싶어질때 마다 격려해 주시고 힘을 주셔서 이렇게 마칠 수 있게 됐습니다. 힘겨운 시간 동안 함께해준 박사과정에 있는 송 창식 선배, 홍 찬선 선배, 최 유진, 안 다영, 박 선주, 염 민규, 조 태근 님께 감사를 드립니다.

논문이 끝나지 않을것이라고 생각했는데 여기까지 올 수 있었던 것은 많은 분들이 도와주셔서 할 수 있었습니다. 이제 그 고마움을 늘 생각하며 조금이나마 갚아가며 살아가야 겠습니다. 부족한 지식과 경험이 쓰여지는 곳에 보탬이 되면 좋겠습니다. 이제 연구할 수 있는 법을 알게됐다는 지도교수님의 말씀을 새기며 성함을 넣지 못한 많은 분들께 감사의 마음을 전합니다.

ABSTRACT

The importance of knowledge creation in economic development has been enormously emphasized in recent years. Inventions are the first step for innovations that leads to further economic growth. Moreover, when new ideas are created endogenously from within a regional system, rather than from outside, they may lead to internally-generated economic growth and development. Accordingly, this study aims to understand 'the process of generating creative ideas' for endogenous regional economic growth. On the basis of data that reflects the perspectives of actual inventors, the researcher adopted both qualitative and quantitative research methods. The qualitative methods were oriented toward phenomenology and were based upon interviews designed to understand how inventors personally experience the process of invention. The quantitative methods were based upon a mail-out survey of inventors and an in-class survey of students. The surveys were designed to test hypotheses about Darwinian theories of creative thought processes. Interview results provide evidence of both Darwinian theory and Lamarckian theory. Survey results reveal that students' perspectives on invention are more consistent with Darwinian theory than are the perspectives of inventors. From these empirical results, the Darwinian hypothesis for the generation of creative ideas is disconfirmed; however these results do not definitely prove Darwinian theory to be incorrect. From a Darwinian point of view, endogenous economic growth led by new ideas takes the form of "blind-variation and selective-retention." Economic development policy based on Darwinian theory should encourage people to generate various ideas and select one of them at the local and individual level. This can also be applied to regional policies that focus on various industries and academic fields. In contrast, Lamarckian theory supports

top-down approach and focuses on few promising industries and academic fields that are designed from centralized planning.

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CHAPTER I

INTRODUCTION

In the mid-1980s, economic growth theorists began to consider knowledge as a critical factor in economic growth, as well as capital and labor. Theorists in economic growth contended that when capital and labor reach their limited productivity, knowledge could lead to further and perhaps limitless economic growth. Hence, the production of knowledge and extension of the limits of knowledge emerged as the keys for economic progress and development.

With the newly found focus on knowledge, innovation became a core phenomenon in economic development (Acs, Anselin, & Varga, 2002b). Innovation was then considered as a primary source of economic development, and as contributory factor in terms of increased numbers of jobs, new products, and productivity. In this regard, knowledge creation may be viewed as the first step in the processes of innovation, involving the application of new knowledge in a marketplace.

Although the importance of knowledge creation has been emphasized in the recent economic development literature, the generation process through which new knowledge is created has not been clearly, persistently and systematically examined.[1] In addition, the process of creating new knowledge has not been integrated theoretically or practically into economic development literatures. Bowen (2007) argued that if knowledge creation contributes so vitally to economic progress, then mechanisms of knowledge creation must be specified to achieve optimum levels of knowledge creation for economic development. Moreover, different mechanisms of knowledge creation may have different policy implications for economic development policies and practices.

One feasible theoretical basis from which to understand the mechanism of knowledge creation is evolutionary theory. In evolutionary theory as applied to biological populations, Darwin's model of random variation and natural selection has been repeatedly confirmed and affirmed by a wide variety of scientists. Darwin's theory stipulates that variation is randomly generated and that individual variants will be naturally selected or rejected by factors embedded within in the environments of the individuals who carry the variants. On the other hand, some scientists also support Lamarckian theory. Lamarckian theorists argue that instructions originating from within an environment and transmitted to biological organisms may be a possible mechanism for the evolution of biological organisms.

In generating new knowledge, Darwin's theory stipulates that the generation of new ideas follows the processes of "blind-variation and selective-retention" (BVSR) (Campbell, 1960). The term "blind" refers to an absence of foresight or prior deliberation in the generation of various ideas. When people confront new problems or old problems that are difficult to solve, people have to go beyond the boundaries of previous ideas and

1 In this paper the inventive idea is considered as a critical form of knowledge creation. In many cases, it will be used interchangeably with knowledge creation.

knowledge (Campbell, 1960). According to Campbell, the basic mechanism through which people begin to generate new and creative ideas is 'blind variation.' Blind variation is characterized above all by a lack of foresight of the future status of various trials. In criticism of this view of knowledge creation, scholars have argued the opposite point that new ideas are generated from 'sighted variation' which is based upon prior knowledge and goals (Sternberg, 1998; Weisberg, 2006). This opposite view of Darwinian theory is in many respects similar to Lamarckian theory, and it is referred to as such in this research.

One way to begin to resolve the gap between these two theories, and so to better understand the process of new knowledge creation, is to examine individuals who generate new ideas. Thus, this study is designed to empirically examine how inventive ideas[2] are generated in the individual mind, as seen from the point of view of inventors. The researcher specifically seeks evidence regarding whether Darwinian or Lamarckian theory is a more likely explanation for the generation process of new ideas. An underlying assumption is that improved understanding about inventive ideas may help policy-makers to design policies that enhance the generation process of inventive ideas that affect economic development in the long-term.

[2] Inventive idea is the critical idea that is the core of the invention. In this paper inventive ideas will be viewed as containing the perspective of creativity.

CHAPTER II

KNOWLEDGE AND ECONOMIC DEVELOPMENT

Prior to the 1980s, capital and labor were considered as the main factors driving economic growth and development. Since then, however, knowledge has also started to receive consideration as being one of these factors. Today's discussions about the knowledge economy emphasize non-physical factors such as skills, technologies, and ideas rather than physical factors such as labors and machines (Stough, 2001).

2.1 Endogenous Growth Theory

Since the 1980s, measures of the productivity of manufacturing and service sectors (e.g., output per worker) have tended to stall. At the same time, information technology has emerged as an economic growth engine that could improve traditional sectors' productivity and open new applications (Harris, 2001). With this trend, knowledge has gained consideration as an important resource for economic growth, largely because knowledge may be characterized by increasing returns (Cortright, 2001; Romer, 1986).

Knowledge has for the past couple decades been considered as a significant factor in economic growth and development (Bowen, 2007; Romer, 1986). Furthermore, knowledge has been considered as a public good that can be accessed by any individual. Knowledge was often not been incorporated explicitly in economic models. For instance, the Solow Growth Model (old growth model), which was the standard model prior to Romer, considers knowledge as a residual. As such, knowledge has not been fully considered as an independent variable that affects economic growth. However, Romer (1986) changed this paradigm by placing knowledge as an explicit endogenous variable.

The basic functional form of the endogenous growth model (New Growth Model) originated from Romer's (1986) model may be rendered as follows:

$$Y = F(K, L, A) \qquad (1)$$

where K represents regional capital, L represents regional labor, and A represents regional technology and knowledge. For an individual firm level, the model may be rendered as follows:

$$Y_j = F(K_j, L_j, A) \qquad (2)$$

where j represents individual firms.

In equation (1), technological knowledge, A, is included as an endogenous variable. Equation (1) shows the production function of industry in a region or country while equation (2) presents an individual firm's production function. The technology embodied in an individual firm, A, is considered to be the economy-wide state of knowledge (Snowdon and Vane, 2005).

In this model, the growth of knowledge is assumed to be a by-product of the accumulation of physical capital goods (Snowdon and Vane, 2005). If one firm invests in physical capital, the productivity of industry increases because other firms in same industry learn from that one firm's investment. These are the positive externalities discussed at length in the economic growth literature (Marshall, 1920; Arrow, 1962; Romer, 1986; Cortright, 2001). Accordingly, on the basis of recognition of positive externalities, the industry as a whole benefits from increasing returns while individual firm does not necessarily do so (Snowdon & Vane, 2005).

Traditional economic theories are based on the assumption of decreasing returns. Decreasing returns imply that at some point the additional inputs of labor or capital will result in a smaller amount of output than previous inputs. Under this assumption of decreasing returns, a firm or a region can continually increase its output by increasing capital and labor, but the effect of the increase of capital and labor inputs will eventually begin to diminish on the margin. In these models technology is assumed to be 'exogenously' given to the production function of a firm (Cortright, 2001; Snowdon and Vane, 2005; Bowen, 2007).

In contrast, the concept of increasing returns implies that continued additional inputs will result in increasing amounts of output. For instance the development of software requires millions of dollars for initial investment, but once the initial copies of the software are produced additional copies will cost nearly zero (Cortright, 2001). Moreover, increasing returns come from the 'endogenous' efforts of entities that seek an improvement in the state of technology and knowledge. This advancement of economic theory is formulated in the New Growth Model (Romer, 1986; Romer, 1994; Stough, 2001).

In contrast to Romer's initial model, which assumed that technological progress is a by-product of capital accumulation, the second iteration of the endogenous growth model added two assumptions: (1) knowledge creation is a deliberate effort which responds to financial incentives, and (2) the two defining characteristics of knowledge are non-rivalry and partial excludability (Snowdon & Vane, 2005).

Non-rivalry. Knowledge is non-rival in that it can be shared with many people at the same time. Knowledge can be produced with nearly zero cost after being initially developed. For instance, the discovery of a new treatment for cancer initially entails high-costs for research and development; but once the new treatment is developed it can be used by many people. This attribute of non-rivalry highlights the importance of property rights for the producers of technology and knowledge (Cortright, 2001).

Partial excludability. Knowledge is partially excludable because the investment in specific knowledge does not return all the benefits to the original investor. For instance, the benefits of R&D for one pharmaceutical company can be protected by licenses and patents. However, this protection is not permanent for the developer. Other pharmaceutical companies may reap the benefits from the investment of the company holding the license or patent. This attribute of partial-excludability enhances the importance of intervention of government policy to promote incentives for investment in R&D (Cortright, 2001).

Discovery from people. Along with the properties of knowledge, some authors have also emphasized the source of knowledge creation. Romer (1994) for instance described the advancement of technological knowledge as follows:

> …… the aggregate rate of discovery is endogenous. When more people start prospecting gold or experimenting with bacteria, more valuable discoveries will be found. This will be true even if discoveries are accidental side effects of some

other activity (finding gold as side effects of ditch-digging) or if market incentives play no role in encouraging the activity (as when discoveries about basic molecular biology were induced by government research grants). The aggregate rate of discovery is still determined by things that people do (p. 13).

Romer (1994) emphasized that discovery is the result of efforts made by people and by their work. If for instance more biologists reside in certain places than others, then the probability of discovery in the field of biology increases in those places. This is because biologists are the source of discovery in that field. Romer (1994) pointed out this can be true even if the discovery is a side-effect of other activities, or is supported by government. A similar point about economic development is made by Florida (2002) in his emphasis upon the accumulation of talented people, especially creative people.

In the endogenous growth model the advancement of knowledge is not considered as given, but rather as the outcome of endogenous economic activity conducted in search of profits. Knowledge in this model is an independent variable whose value is produced within the economic system, and that will affect long-term systemic economic growth.

The endogenous growth literature tends to treat knowledge as if it is partially produced within a regional economic system and not everyone has equal access to it. The growth rate of knowledge is different for different subsystems of an economy and this is a fundamental factor for economic growth. In the endogenous growth framework, economic growth is highly linked to the creation and diffusion of knowledge (Acs et al., 2002b; Bowen, 2007; Cortright, 2001; Stough, 2001).

Marten (2004) also pointed out that a cognitive mechanism must be related with economic development. Marten argued that the properties of knowledge and the generation mechanism for knowledge constitute important and crucial features in economic development. In Marten's argument, the division of labor provides a base for new knowledge creation, but he did not elaborate upon how the new knowledge is created.

2.2 A Model of Knowledge Creation, Invention, Innovation and Creative Idea

Knowledge may be assumed to be created at an individual level (Campbell, 1960). Groups of people can affect knowledge creation processes by putting forth their opinions and ideas, and other people's input can be a factor for the generation of new ideas. However, according to Campbell, the ultimate thought process happens in an individual mind rather than in any sort of group thought. This does not disregard the fact that new ideas may be generated from various sources of input.

The discussion of knowledge creation in much of the economic development literature focuses upon invention and innovation (Bowen, 2007). Invention is arguably the first step in the process of knowledge creation (Popper, 2002). Thus by extension the process of invention is a primary concern in sustaining the competitiveness of companies and regions in a globalizing knowledge economy. Differential rates of invention may help to explain the competitive edge of some regions.

Schumpeter (1934) indicated that invention is different than innovation. Accordingly, when an invention is applied to the market it is an 'innovation.' While invention is arguably a fundamental basis and perhaps even an antecedent for innovation, unless the invention is brought to market it will not foster regional economic growth. Entrepreneurs carry out this process of innovation. It has even become a mantra in recent years that only innovative companies and regions can sustain their competitiveness.

Innovation can broadly be defined as "new combinations of old, tried and true ideas" (Schumpeter, 1934, p.66). While this definition of innovation might include both invention and innovation, different knowledge, skills and abilities are required for each.

Invention requires originality and usefulness in scientific and technological fields. Innovation, on the other hand, starts with an invention that already exists and proceeds to commercialize it and bring it to market in new ways. While different, both phenomena require creativity as the foundation for further development. From this common basis of creativity and creative thought, innovation can broadly be defined as 'combinations of new things.' Knowledge creation can include innovation that seeks 'better ways to do things' and 'learning throughout a firm' (Cortright, 2002).

Creativity may in turn be conceived as the ability or capacity to generate something new. People are creative when they are developing new artistic works. The scientific world requires creative ideas when scientists develop new hypothesis. The business sector requires creative new ideas for further profits. Everyday life demands creative solutions, especially when responding to new problems.

Creative work can be defined as products, processes or ideas that are new. If the ideas or products previously existed, they cannot be considered as creative works. Past this point, there can be two viewpoints on creativity: whether the work is creative to the world or to a person. Being creative to a person means that a person may develop locally novel ideas within the context of his or her own life, yet those ideas may already exist within some other context. In order to be creative to the world, novel ideas need to be new to the world across all contexts. Creative works require creative thought processes (Weisberg, 2006).

In order to examine the processes of knowledge creation, this project examines the generation process of creative ideas as a starting point of invention at the individual level.

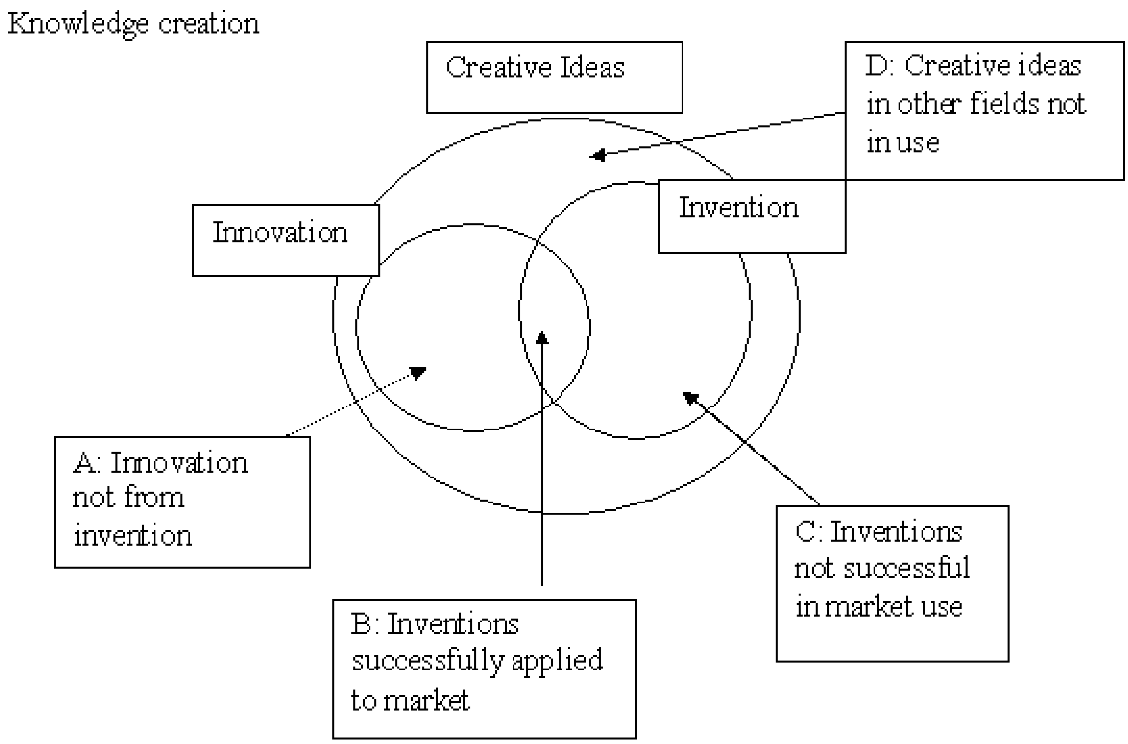

Figure 1. The relationship between knowledge creation, invention, innovation and creative ideas modified from Basberg (1987).

Figure 1 depicts the relationships among knowledge creation, invention, innovation and creative ideas. Knowledge creation is limitless, so it is portrayed without boundaries. Creative ideas are the broadest concept underlying invention and innovation. Creative ideas can be the source for invention, innovation, and new artwork. From creative ideas both invention and innovation can be started. Some inventions are successfully applied to market (portion B), while other inventions are not (portion C).

There are other innovations that do not require inventive ideas, such as an expansion of a new market for a product (portion A). Finally, creative works would not be used for commercial use yet (portion D).

2.3 Theories of Creativity and Methods for Studying Creativity

2.3.1 Unconsciousness in Creative Thought

The concept that past experiences can unconsciously affect creative ideas is called 'unconscious association' (Gedo, 1980). Past experiences can be described as previous needs and conflicts that are unconsciously associated with the present process of creativity. For instance, the creative works of Picasso may have been related to his conflicts with his mother and sister in his childhood (Gedo, 1980).

Many times, creative people have argued that their creative ideas come to them without a clue as to where or why they were formed. Thoughts can occur without a clear realization of where they came from. The concept that thought processes oriented toward obtaining a solution to a problem can possibly originate unconsciously, is called 'unconscious processing.' (Poincaré, 1913) An illustrative example may be found in Poincaré's self-report of his discovery of a solution to a mathematical problem (Hadamard, 1945). Poincaré (1913) reported that the mathematical solution appeared as a sudden realization, which is sometimes called an 'illumination.' Before illuminating the creative thought, there may need to be an unconscious incubation process during which occurs the preparation for accumulating knowledge and information about the problem (Poincaré, 1913).

Creative ideas may also result from a break with the past that requires a leap of insight (Wertheimer, 1982). This break with the past may possibly occur unconsciously since the old ideas cannot guarantee a solution to a current problem, especially when the solution to the problem requires fairly radical ideas that are completely different than previous ideas. The reproduction of past ideas may not produce solutions to new situations. Radical solutions for new problem situations may have different elements in them as compared to previous solutions based upon old ideas, or perhaps different relationships between the constituent elements. For instance, Darwin's natural selection required a different approach than Lamarck's theory, which at the time was the received view. If a solution to a new problem requires more creativity than did solutions to old problems, then it may necessitate a more radical break from past ideas (Campbell, 1960). The works of Poincaré (1913), Csikszentmihalyi (1996), and Simonton (1988, 1999b) are aligned with this idea in that more creative ideas require breaking away from prior knowledge than do ones that mix previous ideas.

2.3.2 Divergent Thinking

Guilford (1950) provided a conceptual and theoretical basis for measuring creative ability and capacity using creativity tests. Divergent thinking may be defined as thinking in a different way than ordinary thinking. Accordingly, breaking from the accepted rule is crucial for creativity (Guilford, 1950). Divergent thinking develops various ideas, and once these ideas are generated, convergent thinking chooses the best one. Highly divergent thinking is positively related with creativity (Csikszentmihalyi, 1996). The explanation for divergent thinking is twofold: (1) it generates ideas that diverge from old ideas, and (2) a different type of thought process takes place, other than the ordinary process. This second interpretation is in opposition to the view that creativity is a product of ordinary thinking (Weisberg, 2006). Guilford's theory of divergent thinking affected the importance of ideational variants in confronting new problems (Simonton, 1999). Guilford also provided a theoretical basis from which to recognize the the importance of personality in terms of creativity.

2.3.3 Confluence Theory

Confluence theories consider various aspects of creative people, such as their knowledge base, their personality, and their creative environments (Amabile, 1983, 1996; Simonton, 1999b; Sternberg & Lubart, 1995). These aspects worked together for generating creative outcomes. These theories emphasize the important elements for creative works but do not provide the process of how it works.

2.3.3.1 Componential theory

Amabile (1983) provided a 'componential theory of creativity.' The first component in this theory is 'domain-relevant skill' which includes knowledge and skill relative to specific domains. This is to say for instance that some people might have more sensitive artistic or scientific ability than others.

The second component is 'creativity-relevant skill' which includes two aspects: abandoning unsuccessful trials and applying heuristics or rules of thumb for creativity such as "When all else fails, try something counter-intuitive" (Newell, Shaw, & Simon, 1962).

The third component is the attitude of an individual. If a person finds intrinsic motivation in relation to a problem, that person might have a higher probability of discovering or inventing a solution to that problem than would a person working for extrinsic rewards (Amabile, 1983).

2.3.3.2 Investment theory

Sternberg and Lubart (1995) suggested an 'investment theory of creativity.' The investment theory of creativity considers various elements of creative people, in which regard it is similar to confluence theory. It is also called the "buy-low and sell-high" strategy. Creative people can see an opportunity that others may not recognize, so creative people can buy the new ideas at a low price. Because creative people recognize and know the potentials for new ideas more than ordinary people, they can sell these ideas at a high price. In this respect, according to this theory, creative people are similar to entrepreneurs who apply new ideas in the marketplace. In order to make the most of these opportunities, people need resources. One set of resources contains the intellectual abilities to see the new opportunity, the ability to see the problem in a new way, the ability to recognize the importance of the problem, and the ability to persuade other people of the value of the ideas. Other resources include knowledge of specific domains, an independent thinking style, and a supportive environment.

Creative work requires that the creative thinker have a relevant knowledge base, creative capacity, and an environment conducive to the development of new ideas. The knowledge base is the accumulation of previous ideas in the domain. In addition to that, creative capacity, such as the ability to see the problem in new ways, needs to be incorporated into the creative product. Finally, the environmental aspects cannot be ignored in the generation of creative ideas, since this element can influence creative ideas negatively or positively.

2.3.4 Evolutionary Theory of Creativity

2.3.4.1 Darwinian Theory of Creativity

The main mechanism of Darwin's evolution theory is random variation and natural selection. The first characteristic of this mechanism is that the new variants are generated *randomly*. In other words, when variants occur, there are no intelligent mechanisms or designs involved. There is no foresight involved in the generation of random variation. After random variants are generated those that are the fittest for the environment will be selected. As a result, the variant that has a persistently higher probability of survival than other variants may eventually evolve to become a new species (Plotkin, 1987).

Blind-variation

In application to creative ideas, the mechanism of natural selection has been called "blind-variation and selective-retention" (Campbell, 1960). 'Blind' refers to the absence of foresight or prior deliberation in the generation of various ideas. In other words, people generate various ideas without any sort of intelligent foresight mechanism. However, 'blind' does not mean that people do not use their knowledge for generating new ideas; they may even in a regimen of blind variation accumulate previous knowledge. The significant point is that in solving problems, even though people use previous knowledge and their intelligence, variants or new ideas are formed blindly. In Campbell's view, when people are faced with a new problem, they should generate blind variants first.

Furthermore, Campbell distinguished between expansion of knowledge and genuine gains of knowledge. For instance, Copernican heliocentrism represents a genuine gain of knowledge, but Edison's light bulb is an extension of previous knowledge. When people confront new problems or old problems that are difficult to solve, people have to go beyond previous knowledge (Campbell, 1960). Therefore, more radical breakthroughs require more random elements.

Selective-retention

From the blindly generated variants, one variant will be selected by the person who faces the new problem, and this will be retained for further use in the future. Ideational variants may go through a similar process of a biological selection process, which is a selection process of variants after random mutations are generated. Variants of ideas will be selected or discarded through their interactions with individuals' knowledge. The individual's knowledge can be a selector in a generation process of creative ideas. Once the individual produces a new idea, the interaction among community members can also be a selection process.

2.3.4.2 Lamarckian theory of creativity

For Lamarck, the adaptive traits of living organisms are caused by the environment. For instance, in Lamarck's view the placement of food in the higher canopy of trees determines that the giraffe's neck will be elongated. According to Lamarck the variation process is initiated and directed in response to environmental factors. Therefore an adaptive trait, such as an elongated neck, is predetermined or instructed by its environment (Plotkin, 1997).

If Lamarckian theory is applied to creative ideas, environmental factors are significant determinants of creative thought and invention. On an individual level, personal knowledge is comparable to the environment. Therefore, personal knowledge is the informer of new ideas and creative works. On a social level, environmental factors, such as lab facilities and community interaction can play a significant role in the generation of creative ideas.

Some theorists of creativity have emphasized deterministic environmental factors such as previous knowledge and goals in the generation process of creative ideas (Perkins, 1981; Weisberg, 2006). In parallel with the Lamarckian theory of evolution, new ideas can accordingly be instructed or given direction by previous knowledge and/or preexisting environments.

2.3.5 Cognitive Theory

Cognitive perspectives see creative ideas as an outcome of ordinary thinking. Unlike other approaches, such as divergent thinking and blind-variation and selective-retention, which is to say ones that focus on unusual thought processes, the cognitive approach focuses on ordinary thought processes. The cognitive approach holds that even though a new idea can have a profound impact, it is invariably the product of an ordinary thinking process.

The cognitive approach was developed by scholars and otherss who emphasize the cognitive process for understanding human nature (Newell & Simon, 1972; Newell, Shaw, & Simon, 1962). These researchers suggested that the thought processes that generate creative ideas are similar to the thought process for all problem solving.

Weisberg (2006) and Perkins (1981) broadened the cognitive perspective of creativity from problem solving to general thought processes. According to Weisberg (2006) creative ideas are the products of general thought process. From this viewpoint, creative ideas can be generated by ordinary thought process, not necessarily problem solving thought processes. In other words, people can think creatively when they are not trying to solve the problem.

From these cognitive theories of creativity, a distinction can be drawn between conscious and unconscious approaches. The cognitive approach differs from other approaches by insisting that creative ideas are the product of ordinary thought process. Scholars who accept the cognitive view argue that creative works are results of the extension of previous ideas and knowledge. They use sketches and drawings of inventions and artworks as evidence for the proposition that creative work results from ordinary thought process.

The cognitive view can be viewed as relatively close to the Lamarckian view of creativity. The cognitive view elaborates the assumption that creativity stems from ordinary thought processes. In these processes previous knowledge can instruct and direct new ideas. According to the cognitive view creativity is most likely to be the extension of previous knowledge that does not require a break from the past. These ideas—support of consciousness and the extension of knowledge—are inconsistent with the Darwinian view of blind (preconscious or less conscious) elements in the generation process of creative ideas.

The Darwinian view emphasizes blind variation as a necessary mechanism for creative ideas. In blind variation, variants are generated without intelligent design even though people may accumulate knowledge for creating variants. Knowledge works as a selector after variants are being formed. In this sense Darwinian view is against the cognitive view; the cognitive view supports the proposition that knowledge (intelligence) is the main source of creative outcomes.

2.4 Methods for Studying Creativity

The following sections examine and elucidate methods and approaches that have been applied to study creativity in the past. These methods can be divided into two groups or approaches: qualitative and quantitative. Qualitative approaches focus upon the elucidation of meaning, in-depth description of cases, discovery of new hypotheses, and description of how experimental or quasi-experimental manipulations or treatments are implemented. It includes self-reports, biographical studies, and historical case studies which emphasize in-depth understanding of creative works.

Quantitative approaches focus on evidence that can be measured and that may be generalized to theories and populations. Historiometric studies, quantitative case studies, and '*in vitro*' studies are all quantitative in approach in that that they emphasize quantitative evidence for studying creative works. For instance, quantitative case studies emphasize sketches and drawings as evidence for creative ideas that are developed from previous knowledge.

In this paper, both qualitative and quantitative methods were used. In-person interviews were used to provide in-depth understanding of the generation process of inventive ideas, as experienced by the inventor. Interview results were also used to suggest ideas for items on the survey instrument. In the quantitative tradition, surveys were used to examine, compare, and gather data informed by the two aforementioned theoretical views, Darwinian and Lamarckian, regarding inventive thought processes. On the basis of these methods, both qualitative and quantitative, the data was interpreted and analyzed regarding the possible causal mechanisms at work in the process of generating creative ideas by inventors.

2.4.1 Qualitative Approaches in Creativity

Self-report. Self-reports use reports from the person who is the subject of the study. Interviews can be one approach for gathering self-reports from subjects. Self-reporting as a source of data for examining theories of creativity has been criticized for several reasons. First, the self-report is criticized as not being accurate because it is a retrospective product. People who make self-reports are required to recall previous thought processes so they might not be accurate (Perkins, 1981; Weisberg, 1986, 1993). This criticism questions the objectivity of findings from self-reports. Second, self-reports are usually not administered by a trained behavioral scientist, so they are less likely to provide valuable data (Ericsson & Simon, 1996). Finally, self-reports are criticized as being less rigorous than quantitative methods such as in testing hypothesis (Weisberg, 2006).

These limitations of self-report and others, such as bias from interviewers and the tendency to want to please the investigator, are threats to the validity of this project. For instance, the interviews were performed by the researcher and some of the expressions and terms used in the interviews were taken from Darwinian theory, and were therefore biased towards it; such as for instance "unexpectedness" in an inventive thought process. However, these threats did not completely invalidate the study. Even though the researcher had no choice but to include some such biased expressions, some interviewees apparently disagreed with the Darwinian elements in creative thought. The inclusion of expressions from both Darwinian and Lamarckian theory will provide balanced view. The fact of this sort of disagreement is difficult to reconcile with the proposition that the terminology used in the interviews predisposed or biased the respondents toward one theory or the other.

The preconscious elements considered within the context of Darwinian theory, especially those related with blind-variation, can pose a limitation on the study. Recognition of these preconscious elements especially may not be forthcoming within the context of the interviews if creative thought processes are indeed Darwinian processes. It might be difficult for creators who have experienced creative thought processes to recognize or remember the preconscious elements within them.

These criticisms of self-reports can be answered in different ways. First, creative people might recall the experiences of creative moments even in retrospect. Different experiences give different memories. People often remember significant things and events clearly. Accordingly, people are more likely to recall the experience of solving problems that they never encountered before. The invention process can be an impressive event for inventors and there is a high probability that they will remember clearly about the relevant thought processes.

Second, data from self-reports can be valuable since the inventor is the informant and is thus a direct source. Even though informants are not well trained about self-expression and reporting about their thoughts and experiences during the process of invention, they have ability to express their past experiences in their own words. For instance, unemployed people can often clearly recall and describe their experience of losing their job. Similarly, parents can describe their feelings and insights from their parenting experiences. Self-reports from inventors can be valuable sources of information about the experiences of creating new ideas and products. Third, self-report can provide in-depth understanding that might be difficult to be obtained by other research methods. Other research methods in some instances have advantages of testability and generalization over self-report. However, these advantages are not the only standard to evaluate the research. Other standards, such as deeper understanding and hidden mechanisms, are also important considerations for assessing social science research. Self-report might provide these features as a complement to other research methods.

Biographical studies. Gardner (1993) studied seven creative people's biographies and categorized their different domains of intelligence. They are Sigmund Freud (interpersonal), Albert Einstein (logical-mathematical), Pablo Picasso (spatial), Igor Stravinsky (musical), Martha Graham (bodily-kinesthetic), T. S. Eliot (linguistic), and Mahatma Gandhi (intrapersonal). From the study of biographies, Gardner was led to some conclusions regarding the importance of having a supportive culture, so that creative people can introduce radical ideas to their environments. In 2003, an eighth intelligence, Charles Darwin (natural environment), was added to this list (Gardner, 2003).

The advantage of biographies over self-reports is that they are based on verifiable historical records (Weisberg, 2006). The major strength of biographical study is the direct study of creative individuals. Moreover, biographies might be the only source of information about people who are no longer living.

Historical case studies. Historical case studies examine creative achievements for understanding creativity. Gruber (1981) studied 'natural selection' as a historical case rather than focusing on Darwin in a biographical study. He examined Darwin's notebooks to understand the process through which Darwin generated the theory of natural selection. Gruber concluded that creative processes are different for all individuals; thus it is hard to generalize by examining his notebooks.

Historical case studies can be considered qualitative inasmuch as they attempt to understand historical cases; but they can also use hard evidence to add some accuracy. Gruber's (1981) study used Darwin's notebooks to supplement his qualitative study. One criticism of historical case studies is that the researcher cannot control information. Historical case studies can be helpful in searching for in-depth understanding, but can be difficult if there is not enough information available (Weisberg, 2006).

2.4.2 Quantitative Approaches

Historiometric methods. Historiometric methods are designed to measure history. For example, Simonton (1999b) studied the number of wars and creative people in history. Simonton found a decrease of the number of art works after a war. Simonton also found that high accomplishments of art works in one generation have positive effects on the number of creative work of the next generation. In another instances, Hayes (1981, 1989) found there is a need for as much as 10 years of experience in preparation for a creative masterpiece. One of the primary strengths of historiometric methods is that they can draw some statistical conclusions if data are available (Weisberg, 2006).

Quantitative case studies. A quantitative case study is a case study that uses some quantifiable data such as drawings and sketches as its data. For instance, the sketches of Picasso's 'Guernica' can be used to see the process of generating creative work. The advantage of quantitative case study is that it uses hard evidence. However, if the researcher chooses one of Picasso's works, the question remains as to the representativeness of a particular piece in reference to his other works, other artists, and to other domains. For defense against this critique, Weisberg (2006) suggested choosing many cases and using various investigators to avoid this generalization problem. It is also difficult to get the right data for examination. For instance, it would be impossible to examine the thought process of Thomas Edison if we do not have any critical data.

***In vitro* investigations**. *In vitro* investigation is a method that tries to reduce the gap between *in vivo* study and experimentation. Researchers using *in vitro* study can extract a core part of the previous invention and present this to a group in a controlled environment. For instance, Dunbar (1995) used the Nobel Prize example of a ‘regulatory gene’ that inhibits a certain function of another gene. He presented this example to two groups of students. One group received more information about the problem than the other group. Students who received more information about the problem had a better chance of finding out the solution that is close to the original discovery of Nobel laureates. The result can be interpreted as supportive of the knowledge and proper information as the key to creativity.

2.5 Research Questions

It is widely agreed that inventive ideas play a significant role in economic development, especially when they are sources for the innovation that, in turn, promotes economic development. Thus, this research examines the generation process of inventive ideas as a core component of the knowledge creation process. The first question of the project is: *how do inventors come up with their inventive ideas?* An improved understanding of the invention process will be elaborated from this first question. In order to test and compare the Darwinian as compared to the Lamarckian mechanism, the second question is: *does the generation process of creative ideas follow a Darwinian or Lamarckian approach?*

CHAPTER III

EVOLUTIONARY THEORIES: DARWINIAN VS. LAMARCKIAN THEORY

3.1 Evolutionary Theories about Biological Systems

There are two distinct theories describing the evolution of living organisms: Darwinian and Lamarckian theory. Both theories may be and have been applied to describe a development of creative thought (Campbell, 1960) and socio-economic evolution (Nelson and Winter, 1992). Darwinian theory is based on the concept of 'random variation and natural selection' as the main mechanism for evolutionary change in biological systems. This mechanism from Darwinian theory has also been applied to creative thought and change in the state of knowledge (Campbell, 1960; Simonton, 1999a; 2005).

The foremost characteristic of a Darwinian mechanism is that the new variants are generated randomly. Hence, when new variants are developed, there are no intelligent designs, mechanisms or foresights involved. After these random variants are generated, those that are the fittest for the environment are determined through processes of 'natural' selection. If a particular variant is selected by the environment and flourishes, it can evolve in to a new species. Similarly, if a particular variant of idea is selected by the subject or society and it flourishes, it can evolve in to new perspectives and bases for knowledge.

For instance, in the Darwinian view, a giraffe's variants are randomly generated through the reproductive processes. One of the offspring may be better adapted to the distribution of food encountered in the environment, particularly in terms of the height of the canopy. The placement of leaves may determine that one variant is more adaptive than another, but the variants themselves are not generated by the placement of the leaves. In contrast, in the Lamarckian view, a giraffe acquires a longer neck as a result of trying to reach leaves that are growing in higher places in the canopy of leaves in the trees, and in turn these acquired characteristics are inherited by the next generation.

Lamarckian theory refers to the 'inheritance of the acquired characters' as the mechanism for evolution (Hodgson & Knudson, 2006; Plotkin, 1997). Lamarck argued that variants are *caused* by deterministic factors within environments. This theory of the 'inheritance of acquired characteristics' is generally rejected by most scientists in biology. Nevertheless, there are still supporters of Lamarckian theory, especially in the areas of immune response and socio-cultural evolution (Laurent & Nightingale, 2001). Detailed description, contrast and application to creative thoughts will be provided in chapter 3.

It is important at this point to further clarify some of the relevant terminology. Darwinism may be contrasted with 'neo-Darwinism.' Both may be contrasted with a Lamarckian view of evolution, but the contrast is a bit different for each. The difference is that Darwinism, broadly construed, does not exclude Lamarckian thought, whereas ‘neo-Darwinism’ does exclude some concepts related to matters of genetic influence, particularly inheritance. Neo-Darwinism is more restrictive than Darwinism to the point that it categorically denies the possibility of the inheritance of acquired characteristics. Thus, while the term ‘Darwinian view’ is used throughout this research to refer to a contrast with Lamarckian theory, the neo-Darwinist view is strictly the one being contrasted. Table 1 shows the distinction between Darwinism and Lamarckism, and a further distinction between the two variants of Darwinism—Darwinism and neo-Darwinism (or Weismannism).

Table 1

Working Definitions of Three Doctrines

Term	Definition
Darwinism	A causal theory of evolution in complex or organic systems, involving inheritance of genotypic instructions by individual units, random variation within genotypes, and a process of selection of the consequent phenotypes according to their fitness in their environment.
Lamarckism	A doctrine admitting the possibility of the (genotypic) inheritance of acquired (phenotypic) characters by individual organisms in evolutionary processes.
Weismannism (or neo-Darwinism)	A doctrine denying the possibility of the (genotypic) inheritance of acquired (phenotypic) characters by individual organisms in evolutionary processes.

Source: Modified from Hodgson (2001)

The neo-Darwinian view and Lamarckian view are used as the framework for this project. For interview the responses from inventors are analyzed in relations with these two theories. For survey items are developed based on these two theories and examined whether the Lamarckian theory can be rejected with the survey data.

Even though debates about Darwinian theory remain today, natural selection is almost universally accepted as a plausible mechanism for biological evolution. It has also in recent years been receiving increased levels of attention in application to human minds and societies (Hodgson & Knudsen, 2006). The origin of creative thought is seen to follow the same initially-random variation and selection mechanisms as characterizes the evolution of biological species.

Moreover, the theory of evolution is viewed as a general theory that can be applied to many different systems. Beinhocker (2006) for instance described the development of social and economic systems and the appearance of novelty in these systems as an evolutionary process. He pointed out that evolution is a general-purpose and highly powerful recipe for finding innovative solutions to complex problems. It is a learning algorithm that adapts to changing environments and accumulates knowledge over time (Beinhocker, 2006).

Beinhocker (2006) emphasized that evolution is not just a metaphor for explaining complex systems, but rather it is the explanation for complex systems. Accordingly, evolution can be viewed as a way of solving complicated problems in innovative ways. This argument that evolution is a process through which innovative solutions occur is linked with the generation process of creative ideas, because many creative ideas can be viewed as new solutions for problems. Moreover, Beinhocker describes how evolution is the principle that leads systems to adapt its environments. Evolutionary process enables us to accumulate knowledge as well. This argument sets the stage for evolution to be applied to creative thought processes and the accumulation of knowledge.

In addition to this general view of evolution, the evolutionary view of the growth of knowledge is chosen as the framework for this project because it is the proper framework to use on the assumption that human beings are an immanent part of the biological system. Plotkin (1997) contended that knowledge can be understood as a general phenomenon that describes behaviors of living organisms throughout the animal kingdom, and human knowledge can be understood as a specific case. Thus, the biological approach to the growth of human knowledge that drives economic development is arguably a suitable one.

Secondly, the evolutionary view of creative ideas is controversial. Review of the literature revealed numerous theoretical debates between the Darwinian view and the Lamarckian view (Simonton, 1999a and 2005; Gabora, 2007). These debates constitute a proper conceptual framework from which to examine which approach is a better explanation for creative ideas in invention From the literature and interview the researcher develops two sets of contrasting conceptual frameworks. Darwinian view is linked with 'unexpectedness', 'serendipity', 'trial-and-error', and 'connecting different ideas.' Lamarckian view is related with 'predictability' and 'extension from previous ideas.'

Finally, the policy implications of Darwinian and Lamarckian theories differ in highly consequential ways, largely related to the regulation and control of knowledge formation in society. The Darwinian view focuses on a blind variation and selection mechanism The associated economic development policies are favorable toward cultivating the circumstances that are most conducive to the generation of a large volume of ideas, enhanced quality ideas, the speed of idea generation, and increased selection standards. These include highly decentralized, self-steering decision processes made at a localized level by individuals throughout the economic system. Moreover, practices of toleration and support for diverse and individually-different purposive economic activities are strategies of Darwinian approach. In contrast, the Lamarckian view emphasizes environmental factors and goal-oriented directions. Thus, the economic development policy of the Lamarckian view is much more favorable toward hierarchical, centralized regulation, control, and planning of economic development activities. In the Lamarckian view, those individuals who are more attuned to the factors inherent within an economic system that cause economic development have superior knowledge and understanding of economic development. Therefore the implication is that such individuals should be identified and appointed to centralized positions of hierarchical power for purposes of planning and investing in targeted regional economic development programs and policies.

3.2 Genotype and Phenotype

In order to elucidate and evaluate these two alternative mechanisms of change and advancement in terms of creative thought, it is necessary to make a distinction similar to the one in biology between the concepts of “genotype” and “phenotype.” In biology, the genotype is comprised of genes that carry information. An example is a gene that codes for brown eyes. The phenotype is a characteristic that will be developed through interactions between organisms and their environments. The brown eyes themselves, as they can be observed by others, comprise the phenotypic characteristic associated with the corresponding genes at the genotypic level.

Accordingly, for Lamarckian inheritance to occur, two processes are required: a mechanism for encoding phenotypic characteristics to a medium of inheritance, such as the gene (genotype), and a way for the phenotypic characteristic to be transmitted to and inherited by the next generation. For instance, a giraffe's effort to reach to higher places on the canopies of trees must result in a longer neck that must be encoded in the giraffe's genes; otherwise the longer neck cannot possibly be inherited by the next generation.

Hodgson and Knudsen (2006) explained the Lamarckian mechanism using the concepts of genotype and phenotype as follows:

> For the comparison [between biology and other applications of evolutionary theory such as socio-economics] to be appropriate, it has at least to be upheld that acquired characters are encoded in genotype and that the modifications in the genotype are passed on to offspring. In fact, Darwin (1859, 1868) himself believed in both these possibilities (p. 345).

In Darwin's original theory, the possibility of passing on acquired characteristics through inheritance was not rejected. One of the reasons is that the distinction between genotype and phenotype was not yet researched and established in Darwin's times of research. However, in modern biology, the possibility of encoding from phenotype to genotype is generally rejected.

The distinction between genotype and phenotype is important when the evolutionary theory is tested. Lamarckian theory is based on that the phenotypic characteristic is encoded to genotype. If this mechanism cannot be not proven, then the possibility of Lamarckian evolution is failed. Therefore the proper unit of genotype and phenotype is the basis for examine creative thought process. Even though possible genotypes and phenotypes have been proposed for development of ideas, it is still in debates. Following sections will provide some of examples of genotypes and phenotypes for development of ideas and socio-economic system.

3.3 Evolution in Socio-economic System

The distinction between genotype and phenotype is necessary for extending the basic logic of biological evolution to a socio-economic level. In broader terms, a genotype is a replicator which carries information. Similarly, a phenotype can be viewed as an interactor between an individual or process and its environment; a phenotype contains an outcome and actual expression (Dawkins, 1976). Hodgson and Knudsen (2006) described how Lamarckian theory can be examined using the genotype and phenotype in socio-economic systems as follows:

> The possibility of Lamarckism at the socio-economic level hinges on the existence of two mechanisms: one that encodes acquired phenotypic characteristics in the genotype and another that conveys the acquired characteristics from social genotype to social genotype (p. 347).

Hodgson and Knudsen (2006) argued that the distinction between genotype and phenotype needs to be established correctly in order to clearly and accurately examine the process of influence from phenotype to genotype. The processes of inheritance need to be established in order to find evidence of whether socio-economic development is more of a Darwinian or a Lamarckian process.

3.3.1 Ideas or Memes as a Unit of Socio-economic Evolution

Meme as Genotype. In socio-economic evolution the "meme" was stipulated as a possible unit that carries information from one generation to the next, comparable in many respects to the gene in biological evolution (Aunger, 2002; Dawkins, 1976; Hull, 1982, 2000). An "idea" is one of the examples of a meme. Hodgson and Knudsen (2006) described the difficulty of conceiving of memes as members of a genotype as follows:

> If the genotype-phenotype distinction cannot be applied, then the Lamarckian description is not meaningful. If it can be applied, then further problems arise. In the case of meme-as-genotypes the further problem is that memes may be modified or acquired, but this is neither the modification nor the acquisition of a characteristic (p. 361).

When considering a meme as an element of a genotype, Lamarckian inheritance can be rejected because to acquire a meme is not necessarily to inherit the characteristic (phenotype). For instance, the idea of democracy can be passed from person to person without necessarily transmitting the moral standards and behaviors characteristic of democracies. Passing the meme can be thought of copying the memes (genotype) without passing the phenotype (Hodgson & Knudsen, 2006).

Meme as Phenotype. A meme may also be considered as analogous to a phenotype (Blackmore, 1999). This means that meme can be thought of as characteristics that will be appeared by genotype. In this case, however, the problem is that that there is no answer as to what might be the possible genotype for memes. If a gene is the genotype of a meme (and the meme is the phenotype), then it is not the Lamarckian process because in general biologist reject the Lamarckian possibility. Therefore, the absence of social genotype makes it difficult to see meme as social phenotype.

3.3.2 Habits or Routines as a Unit of Socio-economic Evolution

Habit as social genotype. Hodgson and Knudsen (2006) contested that habits may be equated with social genotypes. They defined habits as 'disposition and propensity.' Hodgson and Knudsen (2006) considered habit as a genotype and behavior as a phenotype. For instance, the ability to laugh at small things can be a habit, and laughing can be a behavior. However, they reject the Lamarckian possibility as follows:

> A Lamarckian process that is defined in these terms would require that the relevant aspect of the phenotype (an acquired thought or behavior) of the first person was also back-translated into its genotype (habit). This may occur when repeated (phenotypic) thought or behaviours give rise to new or amended (genotypic) habits. But the phenotypic behaviour could be occasional and not encoded in a habit, yet still be imitated by the second person (p. 359).

Habit as the genotype can possibly be viewed as the outcome of a Lamarckian process, assuming that the phenotypic behavior is encoded in the genotypic habit. However, it is problematic when the second person imitates the changed phenotypic behavior not the genotypic habit. Hodgson and Knudsen's (2006) argument is that the imitation of habit is an indirect process; hence the Lamarckian process does not play a significant role in habit replication. If the second person copies the new habit and then shows the changed behavior, it could possibly be the Lamarckian process.

Routine as Social Genotype. The development of business has been viewed as a Lamarckian process. In this view, a company's 'routines' are seen as analogous to genes that carry information in companies. Workers in a company can learn the 'routine' for production and pass it on through an inheritance process to future workers (Nelson & Winter, 1992).

This explanation of business development can be seen as Lamarckian process, because routines can be modified and passed on. However, there is also a question about whether the routine is the right unit of social evolution, and whether it follows a Lamarckian process. Hodgson and Knudsen (2006) rejected the Lamarckian possibility of routines, because "Blueprint transmission of routines is the inheritance of genotypes. There is no inheritance of the additionally acquired phenotypic characteristics of the performed routines" (p. 360).

Overall, Hodgson and Knudsen (2006) rejected the idea that development of business is a Lamarckian process because the routine as genotype did not provide a feasible mechanism for inheritance of an acquired characteristic. In contrast, the Darwinian model does not have this shortfall. Hodgson and Knudsen (2006) argued that Darwin's original theory might accept the possibility that a social phenotype (company) can affect social genotype (routines) as in Nelson and Winter's (1982) model. However, much as modern Darwinian theory rejects the possibility that phenotypic characteristics may be encoded in terms of an underlying genotype, so this project rejects the possibility that social phenotype could be encoded into social genotype. This is similar to the position taken by modern neo-Darwinian theory.

The concept of an idea or the broader term meme as a unit of social evolution does not clearly provide answers for Lamarckian processes. If the characteristic (expressed outcome or phenotype) can be encoded to an idea or a meme, and the copied idea can provide acquired characteristic to the next generation, then knowledge creation can possibly be a Lamarckian process. This possibility, however, is rejected because meme as genotype does not provide same phenotype and meme as phenotype does not provide possible genotype (Hodgson and Knudsen,2006). For present purposes the implication would be that it remains difficult to examine whether or not knowledge creation is a Lamarckian process, and it apt to continue to remain so until we can find the proper distinction between genotype and phenotype in socio-economic evolution. The definitive unit of socio-economic system that is prerequisite for Lamarckian process has not been agreed yet.

3.4 Lamarckian Theory of Creative Ideas

Lamarck's evolutionary theory is deterministic. For Lamarck, the adaptive traits of living organisms are generated by the environment. For instance, the placement of food in the higher canopy of trees determines that the giraffe's neck will be elongated. The variation process in Lamarckian theory is directed in that an adaptive trait is predetermined or instructed by its environment (Plotkin, 1997).

Some theories of creativity have emphasized deterministic environmental factors such as previous knowledge and goals in the generation process of creative ideas. In parallel with Lamarckian views of biological systems, new ideas can be instructed from previous knowledge and/or environments. These theories can be viewed as Lamarckian in terms of creative ideas.

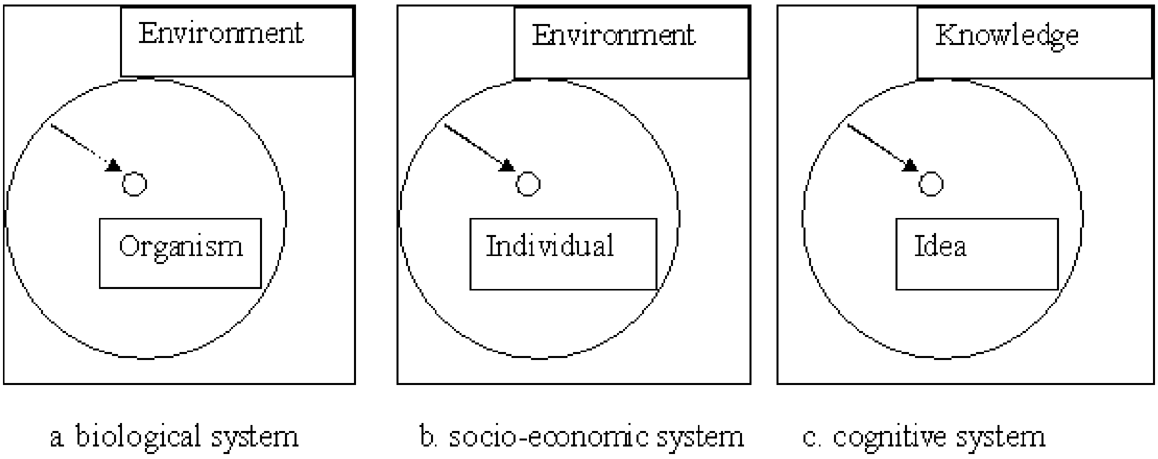

Figure 2. Lamarckian mechanism of instruction for biological organisms and ideas.

Figure 2 shows the environmental effects on organisms, individuals, and ideas. In cases of inventions, the knowledge of an individual is analogous to the environment. As Lamarckian evolution theory argued that deterministic environmental factors instruct adaptation in living organisms, so it is in thought processes. Lamarckian views stipulate that prior knowledge can instruct new ideas deterministically. These views also stipulate that goals and directions produce new ideas. By insisting on this progression, a Lamarckian view contests the Darwinian assumption of blind variation of thought.

Drafts of artwork and invention are often mentioned as evidence for Lamarckian views of creative ideas. The argument of the Lamarckian view is that the sequences of drafts show the sequence of the development of ideas (Dasgupta, 2004; Weisberg, 2006). For instance, the sketches of Picasso's *Guernica* and the sequential drawings of the steam engine are presented as evidence in favor of the Lamarckian view of creative ideas.

From the view of Lamarckian evolutionary theory, the future of new ideas can possibly be predictable. Since the variants of ideas are generated from prior knowledge, it is possible to pre-determine which idea will be developed and will be successful. In this view, new knowledge will come from ideas and sources with a past history of better accumulation of knowledge.

3.5 Darwinian Theory of Creative Ideas

3.5.1 Basic Mechanism

Campbell (1960) pointed out the commonality between trial-and-error problem solving and natural selection in evolution as follows:

> The general model for such inductive gains is that underlying both trial-and-error problem solving and natural selection in evolution, the analogy between which has been noted by several persons (e.g., Ashby, 1952; Baldwin, 1900; Pringle, 1951)" (p. 381).

Campbell's point is that natural selection and problem solving can both be based on trial-and-error. In biological evolution, variants are generated without intelligent design, and then one of the variants will be selected or rejected by the environment with which they interact. In the case of a real gain of knowledge, people generate a new and creative idea and the idea survives or not on the basis of trial-and-error.

Campbell (1960) referred to Bain (1874) who used the phrase "trial-and-error" in application to thought processes. Bain (1874) described the creative thought process as follows:

> The great discovery of Daguerre, for example, could not have been regularly worked out by any systematic and orderly research; there was no way but to stumble upon it.… The discovery is unaccountable, until we learn that the author… got deeply involved in trials and operations far removed from the beaten paths of inquiry (p.595).

Bain (1874) contended that great discovery could not be possible by systematic and orderly research. This unsystematic element of discovery can be seen as essentially the same as the line of thought behind Campbell's main arguments for creative thought as the product of trial-and-error. Bain (1874) used the term 'stumble upon' which describes discovery as an unanticipated and unaccountable event.

Campbell (1960) referred to Souriau (1881) as another source for stipulating that there exists a chance element in creative thought process. Souriau (1881) contended that the starting point for the creative thought is problem recognition, and that this is a critical element. Campbell highlighted the role of chance in invention.

The discovery of a new problem can accordingly be fortuitous. The role of logic in creative though is diminished, and the increased emphasis upon the importance of chance implies that invention or discovery involves an element radically different than previous knowledge. Souriau pointed out that chance is the first principle of invention as follow: "it is what has produced method, nourished it, and made it fertile" (qtd. In Campbell, 1960, p.385).

Souriau (1881) described the relation between the degree of invention and chance. The more radical the inventions, the more chance elements are involved. This point is consistent with Campbell's (1960) arguments about 'true gains of knowledge.' If new problems are encountered, existing knowledge cannot provide a clue, so the contribution of chance will be increased.

Souriau (1881) also suggested that large numbers of combinations are necessary for coming up with solutions for problems:

> Even genius has need of patience. It is after hours and years of mediation that the sought-after idea presents itself to the inventor. He does not succeed without going astray many times; and if he thinks himself to have succeeded without effort, it is only because the joy of having succeeded has made him forget all the fatigues, all of the false leads, all of the agonies, with which he has paid for his success (p.43).

Souriau (1881) contended that invention requires a tremendous number of ideas as the precondition for worthwhile new ideas. It is possible that as the number of combinations increases, the probability of coming up with a solution increases. Moreover, upon successfully solving a problem, scientists are apt to forget all the trails and difficulties that they have been through, because of the joy they experience when they finally end the process of generating creative ideas.

Campbell (1960) referred to Ashby (1952) for his rationale regarding the substitution of successful ideas for unsuccessful ideas:

> Just as, in the species, the truism that the dead cannot breed implies that there is a fundamental tendency for the successful to replace the unsuccessful, so in the nervous system does the truism that the unstable tends to destroy itself imply that there is a fundamental tendency for the stable to replace the unstable (Ashby, 1952, p. vi).

Ashby's (1952) argument can be viewed as an analogy between organic evolution and the evolution of thought processes in terms of the replacement of unsuccessful ideas. The variants with better adaptive traits will be selected for by the environment. For thought processes, the stable variants that have a better fit to the criterion of the problem or knowledge will be selected and replace the unstable variants.

Campbell (1960) referred to Ernst Mach as the source for the variation and selection model. Mach (1896) stipulated and elaborated upon the process of selection of better-fitting variants and suggested that the process will lead people to believe that the creative thought process is a deliberate process.

> After the repeated survey of the field has afforded opportunity for the interposition of advantageous accidents, has rendered all the traits that suit with word or the dominant thought more vivid, and has gradually relegated to the background all things that are inappropriate, making their future appearance impossible; then from the teeming, swelling host of fancies which a free and high-flown imaginations calls forth, suddenly the particular form arises to the light which harmonizes perfectly with the ruling idea, mood, or design. Then it is that which has resulted slowly as the result of a gradual selection, appears as if it were the outcome of the deliberate action of creation (Mach, 1896, p.174).

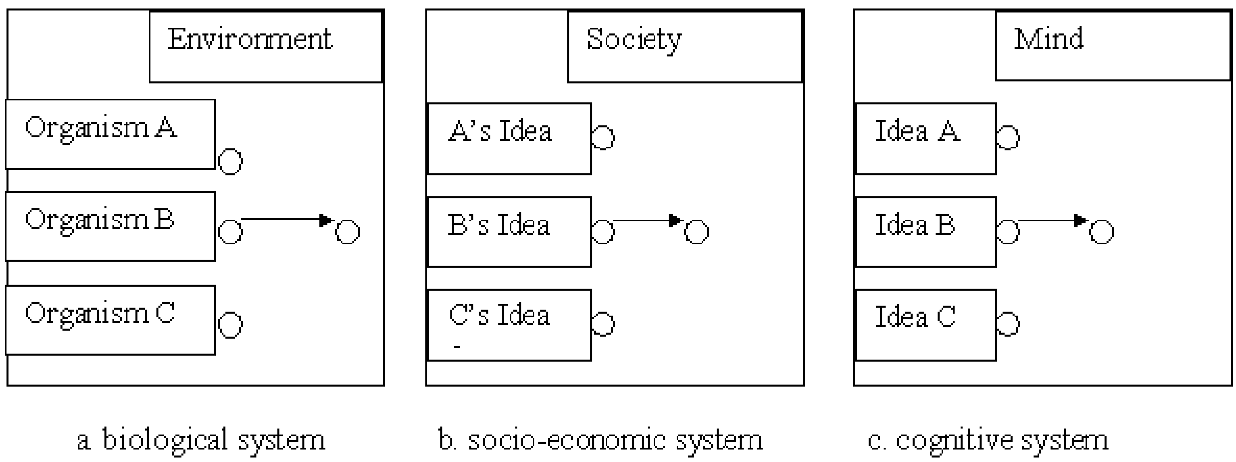

Figure 3. Darwinian mechanism of selection in organic evolution and knowledge.

Figure 3 describes the analogy between biological, socio-economic, and cognitive systems in Darwinian theory. In a biological system, an organism that fits into an environment will be selected, and will 'survive.' In Darwinian view, the giraffe's adaptations are the culmination of many randomly generated variants, each of which happens to fit the distribution of food in the giraffe's environment. This variant is thus favored by the environment. When applied to creative ideas, this Darwinian evolutionary mechanism takes the form of "blind-variation and selective-retention" (BVSR) processes (Campbell, 1960, p.380).

In Campbell's view, when people generate new knowledge, they first generate blind variants of ideas. From these blindly generated variants, one variant is selected through interaction with the systems it relates to, and then retained for further use. From the pool of blindly generated variants of ideas, one idea is selected by a socio-economic system or mental process. This selection process is comparable with the selection of the fittest from variants in biological evolution. In a thought process, more stable ideas will be selected from among a large set of competing ideas (Ashby, 1952).

3.5.2 Three Conditions and Themes for Knowledge Creation

Like natural selection in biological evolution, three essentials need to be developed for Darwinian-type knowledge creation. Campbell pointed out that "three conditions are necessary: a mechanism for introducing variation, a consistent selection process, and a mechanism for preserving and reproducing the selected variations" (Campbell, 1960, p.381). First, an individual should introduce a new variant in some way. Ideas and feedback from other people might help to generate variants. Exposure to different cultures would produce new variants. This production of new variants will eventually happen within the individual's mind. It is commonly referred to as 'creative thought.' Second, an individual must have a 'consistent selection process.' An individual's knowledge, or the knowledge held by society overall, can select or reject various ideas. This is analogous to natural selection in environments. Third, an individual should have a mechanism for retaining the selected variants. We need to have some mechanism of retaining the selected ideas for further development.

Campbell (1960) developed three themes in knowledge creation. The first theme is that BVSR applies to all increases in knowledge and BVSR is the fundamental mechanism for 'true' increase of knowledge. By 'true' Campbell meant a real gain of knowledge. Campbell (1960) stated that "a blind-variation-and-selective-retention process is fundamental to all inductive achievements, to all genuine increases in knowledge, to all increase in fit of system to environment" (p. 381). This process of blind variation and selective retention will be referred to as a BVSR process in the following paragraphs.

The second theme is that a 'shortcut' to full BVSR process can only be accessed after the knowledge is initially gained. The shortcut, which reflects already achieved wisdom, is originally gained by BVSR process. Campbell (1960) stated, "the many processes which shortcut a more full blind-variation-and-selective-retention process are in themselves inductive achievements, containing wisdom about the environment achieved originally by blind variation and selective retention" (p. 381). Campbell pointed out that original achievement of knowledge is driven by full BVSR process and once it is achieved this can be used similar to a shortcut.

The third theme is that a shortcut process also has its own BVSR process. Campbell stated the third theme as: “In addition, such shortcut processes contain in their own operation a blind-variation and selective-retention process at some level, substituting for overt locomotor exploration or the life-and-death winnowing of organic evolution” (Campbell, 1960, p.381). Even though one can achieve wisdom and use this achieved wisdom as a shortcut to full BVSR process, a BVSR process can still be involved.

3.5.3 Blind Variation and Gains of Knowledge

Campbell (1960) implied the distinction between expansion of knowledge and genuine gains of knowledge. This distinction can be understood as different degrees of invention or discovery, such as radical discovery of Copernican heliocentrism vs. the extension of previous knowledge, such as Edison’s light bulb. Campbell (1960) described this real gain of knowledge as follows:

> Blind variation has represented repeated “breakouts” from the limits of available wisdom, for if such expansions had represented only wise anticipations, they would have been exploiting full or partial knowledge already achieved. Instead, real gains must have been the products of explorations going beyond the limits of foresight or prescience, and in this sense blind (p. 380-381).

If the ‘breakouts’ are wise anticipations, then the ‘breakouts’ involve use of existing knowledge which can possibly be ‘foreseeable’ or ‘prescient.’ On the contrary to this wise anticipation, the real gain of knowledge must be ‘blind’ because the breakout needs to go beyond the limits of the previous knowledge.

In the case of real gain of knowledge, whether an idea will be successful or not cannot be judged in advance. Campbell (1960) explained the blindness of successful and failed ideation as follows:

> In the instances of such real gains, the successful explorations were in origin as blind as those which failed. The difference between the successful and unsuccessful was due to the nature of the environment encountered, representing discovered wisdom about that environment (p. 381).

If the variants of ideas are blind, then it is false to argue that one can predetermine which variants will be successful. For instance, scientists come up with various conjectures of treatment for cancer, yet it is not identified at the front which one of the ideas will eventually prove to be the cure for cancer. Cancer researchers generate plenty of new ideas and one of them which fit to scientist's knowledge will be selected or rejected. Therefore, the knowledge of scientists is comparable to an environment that select organism in biological evolution. This selected idea will be tested again by other researchers.

3.5.4 Connotations of Blind Variation

Independence of variations to environments. One of the conditions for blind variation is that all variants need to be independent from the environment in which they arise. Campbell (1960) stated this as follows: "the variants must be independent of the environmental conditions of the occasion of their occurrence" (p.381). For instance, in organic evolution the variants of giraffes' neck are independent of place of the leaves. Campbell (1974) quoted Dobzhansky for random mutation in organism: "Thus Dobzhansky (1963, p.211) says 'Mutations do arise, apparent in all organisms, and they arise at random with respect to their usefulness to their carriers'." (qtd. In Campbell, 1974, p. 150). Similar to random variation in biological evolution, in cognitive evolution the variant ideas of a cure for cancer could be independent to the problem of cancer. We do not know in advance which idea will be selected or rejected for the cure for cancer.

Campbell (1974) stated the following about the first condition:

> An important implication of this is that the order of occurrence of the variations be independent of their adaptiveness, that a useful variation be no more likely to occur early than late, etc. … But even were (and where) some degree of adaptive correlation to be found between a new environmental setting and the mutations which are concomitant with it, or, more likely, between a new puzzle situation for an animal and the responses it emits, this neither violates the model nor provides an explanation of an eventual improvement of fit. For this adaptive bias in explanation (other than preordained harmony) is through some past variation and selective retention process. Furthermore, if the animal's partially intelligent floundering is replaced by a still more efficient or errorless response pattern, this gain in fit is not at all explained by the prior useful non-randomness. Rather, it can only be due to a selection from among the limited range of intelligent but imperfect variations those that happen to be still more adaptive (see Dobzhansky, 1963) (p. 150).

The implication of independence of variations to their environment is that useful variation could occur later because the usefulness of any given variant is independent of environments. Furthermore, even though there is an adaptive correlation between subjects and environments, this does not violate the model nor explain an improvement of fit. This adaptive fit is also acquired from previous variation and selective retention process. Moreover, the replacement by efficient intelligence is also explained by selection from among imperfect variations.

Variability beyond adaptiveness. Campbell (1960) defined the second condition for 'blind' as follows:

> A second important connotation is that the occurrence of trials individually be uncorrelated with the solution, in that specific correct trials are no more likely to occur at any point in a series of trials than another, nor than specific incorrect trials. (p. 381).

This condition can be divided into two parts: 1) The correct trials can happen at any arbitrary point in time, and 2) correct trials are no more likely to happen compared to other trials. We cannot foretell when the correct trials will occur. Moreover, if we do not know a solution yet, the probability of generating right solution is same with other thought trials.

Campbell (1974) described this condition in more detail as follows:

> …a cat in Thorndike's puzzle box is far from random in his response emission, primarily because of innate and acquired preferences for certain responses over others, a partial wisdom appropriate to the ecology of past traps in evolution and ontogeny, but also because of structural biases against generating certain kinds of novel variations. If these predilections are strong enough, the cat will not solve the puzzle box, because Thorndike has deliberately designed it to be puzzling, to have a counterintuitive solution. In particular, the cat's strong expectation that locomotor permeability walls that light is coming through, have been rendered

> counterproductive by Thorndike's puzzle, the cat has to generate some very low probability responses that it cannot generate 'wisely'. After frustrating itself with stubborn repetitions of 'intelligent' responses, it may be 'by chance' and 'inadvertently' (Guthire, 1954; Guthire & Horton, 1946) generate a number of low-probability responses, among which may be one that releases the trick door. Equiprobability is both descriptively wrong and analytically nonessential. But variability reaching into responses beyond the already adaptive is essential (p. 148).

Campbell's argument is that variations can be restricted by partial wisdom and structural biases. This requires producing some low-probability responses which cannot be generated wisely. One of these responses could lead to the solution.

Uncorrelated subsequent trials. Campbell (1960) described the third condition as follows:

> A third essential connotation of "blind" is rejection of the notion that a variation subsequent to an incorrect trial is a 'correction' of the previous trial or makes use of the direction of error of the previous one. (Insofar as mechanisms do seem to operate in this fashion, there must be operating a substitute process carrying on the blind search at another level, feedback circuits selecting 'partially' adequate variations, providing information to the effect 'you're getting warm', etc)… (p. 381).

In another article, Campbell (1974) argued that the subsequent trial is not the correction of a previous incorrect trial as follows:

> Another useful connotation of random is that prior runs do not affect subsequent ones, and in particular the rejection of the notion that the wisdom of later variations is improved by the knowledge of the failure of the earlier ones. Where descriptively this does happen, it is due to additional knowledge. If there is known to be a solution and a finite number of alternatives, then the elimination of wrong alternatives improves the chances of successive guesses… (pp. 150-151).

Campbell's contention is that an increased probability of coming up with a successful solution can happen only when there is additional knowledge. Additional knowledge will eliminate unsuccessful trials that would otherwise decrease the probability of successful guesses.

3.5.5 Counter-evidence and Evidence of Blind-variation

Weisberg (2006) argued that invention of the light bulb by Edison constitutes counter evidence to the Darwinian approach. From the Lamarckian view, the invention of the light bulb is an extension of previous research. Edison used a platinum burner because the previous research using a carbon burner failed. Edison's approach was an attempt to make a better vacuum to last longer than the platinum burner. However, the improved vacuum a using platinum burner was not successful. Edison returned to a carbon burner and succeeded. From the Lamarckian view, there was no break from the previous ideas; hence Edison's contribution to the invention of the light bulb was not a blind variation process.

In the case of the light bulb, the failure of a platinum burner led Edison to use a carbon burner. The failure led Edison specifically to use a carbon burner with an improved vacuum. Therefore, the previous error of using a platinum burner was corrected in the subsequent trial in which a carbon burner was used. This violates the third condition of blind variation; the successful trial was stipulated as a result of the information that led to the rejection of the previous incorrect trials.

However, from the Darwinian view, there is some evidence of a trial-and-error process. Edison used a carbon burner first, and he then turned to a platinum burner, because he could not improve the vacuum when he first tried a carbon burner. Even though he improved the vacuum, the platinum burner was not successful. Knowing this, Edison returned to a carbon burner, only now with an improved vacuum. This process can be seen as trial-and-error process (Darwinian) in that he could not predict successful results.

A well-known example of BVSR process can be found in the occurrence of solutions to scientific problems. Mathematician Henri Poincaré was looking for the solution for the problem known as the "Fuchsian function" for fifteen days. Poincaré came up with the solution when he was away from the problem. Darwinian scholars can argue that the solution for the problem was developed blindly in various forms of ideas, and that one of the stable solutions came to the mathematician's mind through the selection process (Hadamard, 1945). That is why the mathematician did not realize how he came up with the solution. Based on Campbell's writings, Simonton (1999) applied other external elements to creative ideas such as the effect of war in terms of generating art work.

On the basis of the assumption of blind variation, the Darwinian view implies that the future of new ideas is unpredictable. Since the variants of ideas are blindly generated, it is not possible to identify in advance, prior to trial-and-error processes in which the idea is tried in application, which of the range of ideas will prove to be successful. For instance, scientists in cancer biology face many questions that have not been resolved, and they have no rational or scientific knowledge about where the new idea cures cancer will come from and which one of all the possible ideas will be successful.

Within the context of economic development, this logic is, of course, very unsettling. Insofar as the course of economic development is strongly influenced by the growth of knowledge (as per the endogenous growth model), and insofar as the future growth of knowledge is impossible to predict using the rational or scientific knowledge available only today, we cannot, therefore, predict the future course of economic development. Among other things, assuming that this view is correct, rational economic development planning and policy is at best quite difficult.

3.5.6 Selective Retention

Once variants are produced, they are selected or rejected by selectors. Biological variants are selected or rejected by interaction with their environments. Ideational variants may go through a similar process. Accordingly, ideas will be selected or discarded through their interactions with the individuals' knowledge and beliefs. Knowledge and beliefs can be selectors for new ideas, and they bear upon the new knowledge generation process. Selectors can be scientific laws, personal values, and interaction among community members. Selectors can be found in the 'internal structure' of a system or 'thought about that system' (Bowen, 2007; Heylighen, 1997).

In selection processes, general knowledge and specific expertise can be standards that 'weed out' unproductive ideas (Campbell, 1960). General knowledge is common knowledge that has been accepted in the domain such as Geocentrism. Specific knowledge might include for instance the mechanism of planets' movements. However, sometimes scientists have to reject common beliefs to come up with new ideas and theories.

Vicarious selection. Bowen (2007) referred to Bartley to explain vicarious selection. Bartley (1987) explained vicarious selection as follows:

> Take radar as an analogy. Radar is used, by a ship, for instance, as a substitute for movement, i.e., going and looking directly. Instead of exploring its environment directly, with all the attending risks, the ship sends out radar and perhaps sonar. The radar beam is emitted blindly, and is selectively reflected from objects, their opaqueness to the wave band vicariously representing their impenetrability. Trial and error is thus removed from the full movement on the part of the organism and is vicariously invested in the radar beam. Similarly with vision, where an environment far beyond the range of probing touch can be represented vicariously in the image in the visual cortex. This image may be utilized in a vicarious trial and error search or consideration of potential movements, and itself works as an error-eliminating control over movement. Successful movements in thought may be put into overt movement (qtd. In Bowen, 2007, p. 32).

Bartley's (1987) argument of vicarious selection can be summarized in two points. Firstly, knowledge can be seen as analogous to 'radar' that searches a set of imaginable possibilities for new ideas. As radar searches possible obstacles, our knowledge can test whether a new idea is plausible or not by using what we already know. Secondly, this vicarious selection works for eliminating errors. Radar will be used for detecting objects and obstacles. Likewise, existing knowledge will be used for eliminating implausible ideas.

3.6 Criticisms of Darwinian Theory of Knowledge Creation

3.6.1 Blindness

Another main criticism of Campbell's theory focuses upon the concept of blind variation. The opponents of blind variation insist that 'prior knowledge' is required for knowledge creation. From previous experience the subject can have knowledge for similar situations (Quine, 1969). Moreover, the human mind tends to generate correct hypothesis in a way that is reminiscent of instinct (Peirce, 1958). The use of heuristics can also be seen with this line of thought that people use 'rule of thumb' to find out right solution (Simon, 1970). When people generate variants of ideas, prior knowledge is involved in the thought process so it is 'sighted variation' (Sternberg, 1998).

However, from the Darwinian camp, this prior knowledge is the product of BVSR process. In order to create knowledge, the thought processes follow the prototypical BVSR process (Campbell, 1960). The opponents of Darwinian theory do not provide any alternatives that explains the way of getting the prior knowledge (Gamble, 1983).

In terms of blindness, Campbell contended that people generate new ideas without the knowledge of whether the new idea will be worked out or not. In order to create new knowledge, inventors have to go beyond the limits of current knowledge. The argument that new knowledge is based upon previous knowledge is not debatable in the Darwinian view. If we do not know a solution, then we have to go beyond the limits of knowledge. Blind variation means that when an individual has an idea that goes beyond the limits of the current knowledge, then the new variants of ideas will be blind for future status and blind for how it will be formed.

Lamarckian theorists insist that ideas and artifacts are generated from goals and designs. This is the basis of their opposition to Darwinian theory (Dasgupta, 2004; Ziman, 2000). In invention processes, new ideas are developed according to these goals and designs. From these goals and designs, new ideas are formed with full cognizance of the future success, and goals and designs direct new ideas.

Dasgupta (2004), for instance, referred to three cases of creative ideas. James Watt's "Separate Condenser", Jagadis Chandra Bose's "Monistic Thesis", and Pablo Picasso's "Guernica." He argued that each of these three cases were goal-driven and knowledge-driven in contrast to blind variation of the Darwinian view. In another example, Weisberg (2006) argued that the knowledge of Watson and Crick is the main source for the discovery of the DNA structure. This can be an example of the Lamarckian view, because Watson and Crick's knowledge can instruct the discovery of DNA structure.

However, the sequential development of ideas is not enough to refute the Darwinian view of blind variation. In other words, scientists, artists and other creative thinkers might blindly create new ideas when they were facing problem situations. Darwinian scholars may argue that Watson and Crick blindly generated various thoughts to form their new ideas and selected one from those blind variants. Moreover, the final steps of discovery of DNA structure involved some evidence that was consistent with the Darwinian view, specifically trial-and-error of different DNA structures (Weisberg, 2006).

Some Darwinian scholars believe that new ideas heavily rely on previous knowledge. The achieved wisdom and designs will be used for reducing the search space for solutions of novel problems (Ziman, 2000). The argument of the Darwinian view is that even though people can rely on previous knowledge, previous knowledge is not sufficient for the generation of new ideas. Previous knowledge can be analogous to radar. It is used as a selector not as an informer. Using radar can reduce the possible search spaces but it still does not tell in advance which direction the object will come. With the previous knowledge, we still do not know where and how the breakthrough idea will come.

3.6.2 Ignorance of Human Volition

Darwinian views are also criticized for not considering the volition of human beings. Specifically, the concern is that people's will power is involved in a creative process, and since willpower is exercised in pursuit of conscious purposes manifest within the minds of individuals, the process of exercising willpower is in some ways inconsistent with blindness. For instance, in the Lamarckian view, Watson and Crick's self-steered research direction in DNA research affected the finding of the double helix structure (Weisberg, 2006). The idea here is that in the Lamarckian view, the volition of scientists, not random events, constitutes the main causes for scientific breakthroughs (Gruber, 1989).

In response to this critique, Simonton (2005) claimed that "motivated persistence" is a part of the Darwinian framework. Inventors can pursue a project that is based on their goals. The fact that the origins of their ideas are found in blind variation does not stop them from following goals related to their problems. However, volition itself cannot guarantee the generation of viable new ideas. More than willpower or volition is involved in invention. Focusing on the problem that needs to be solved will help, and especially sustained focus, but volition alone cannot reach to the solution of the problem.

3.7 Conceptualization of Darwinian and Lamarckian Approaches

The main difference between the two theories is in the way that they rationalize the source of novelty (new ideas). Darwinian theory assumes that evolution operates upon novelty that stems from random events. When Darwinian evolution is applied to creative thought, these random evens are specifically termed 'blind variation.' In contrast, a Lamarckian view argues that deterministic environmental factors cause the novelty.

In Darwinian theory, random variation in a gene pool first determines the length of giraffe's neck, and the longer necked giraffe proves to be adaptive under the environmental conditions in which longer necked giraffe is more fit in terms of the distribution of food. On the other hand, in Lamarckian view, the higher place of the food causes the longer neck of giraffe.

3.7.1 Darwinian theory

From the Darwinian view, new variants are blindly generated. Thus, from the point of view of Darwinian theories, elements of unexpectedness, serendipity, trial-and-error, connecting different ideas, chance, sub-consciousness, and random-generation and knowledge-selection are expected. Blind variation means that the generation process of variants involves uncertainty and/or sub-consciousness in the creative thought process (Campbell, 1960; Simonton, 1999a; Weisberg, 2006).

Unexpectedness: If creative ideas are formed with blind-variation, the creative thought process is more likely linked with unexpectedness of finding out new ideas. When ideas are formed blindly people who went through creative thought processes difficult to expect what will come out of creative thought process.

Serendipity: Serendipity is related to the creative process as a side effect or unaccountable process that inventors experience as a fortunate moment. After thinking about the problems, creative ideas can come from out-of-blue (Hadamard, 1945).

Trail-and-error: When there are problems that an individual has never encountered before, the best strategy can be trial-and-error. And this strategy would be the only option that is similar to variation-and-selection mechanism (Campbell, 1960).

Connecting different ideas: Sometimes a mixture of two very different ideas can yield creative ideas. Moreover new ideas can be made, when the old idea is applied in new ways. This can be related with Darwinian theory, because mixtures of two different ideas or applying old ideas in new ways can result in unexpected discovery (Campbell, 1960).

Random-generation-and-knowledge-selection: This concept is similar to those in natural selection in that variations are generated randomly and only some of them are selected by the environment. In analogy to biological systems, variants of ideas are generated randomly and only some of them are selected by knowledge.

3.7.2 Lamarckian theory

In contrast to Darwin, Lamarckian theory emphasizes successive phases of development of new ideas, rejecting spontaneous and uncertain elements. From a

Lamarckian view, there are only conscious elements in a generation process of creative ideas. Lamarckian theory is related with predictability and extension from previous ideas.

Extension from previous ideas: If a creative idea is generated through Lamarckian processes, then that new idea needs to be informed from previous knowledge. Because old knowledge works analogously to the operation of the environment in biological evolution, old knowledge should inform the generation of new ideas. Therefore the previous ideas are the main sources of novelty for creative ideas (Weisberg, 2006).

Predictability: If new ideas are informed by previous knowledge, then the new idea could be predictable by examining accumulation of that previous knowledge. Moreover, inventors might experience that the generation of new ideas were predictable.

3.8 Difference between Darwinian and Lamarckian theory

The difference between the two theories is over the question about whether the new ideas can be anticipated or not. Scholars who view creativity and invention from within a Darwinian framework argue that new ideas are not predictable; variants of ideas are blind to their future status when they are formed. Within the context of economic development, this implies that it is not possible for centralized economic development planners and policy makers to predict successful new ideas, and that instead such decisions should be made at a level that is as decentralized and local as is possible. On the other hand, scholars of the Lamarckian view argue that new ideas can have predictable futures, since they follow from the instruction of prior knowledge and people's direction. If the process of invention is predictable, then it is expected to come from certain directions. Within the context of economic development, this implies that the predictably successful new ideas can be funded and supported by centralized economic development planners and policy makers.

To reiterate the preceding, the contrast between Darwinian theory and Lamarckian theory can be summarized in terms of the nature of the process of producing novelty. From the Darwinian view, blind variation is the mechanism for new ideas. In contrast, the Lamarckian view proposes that new ideas originate through deterministic cause-and-effect relationships, caused by elements within the environment.

3.9 Arguments on Creative Products

Debate over Picasso's Guernica. Simonton (2007) concluded that the generation process of Guernica can be seen as a Darwinian process that is led by blind variation and selection. In his study, five judges arranged seventy-nine sketches of Guernica in sequential order. From this experiment, Simonton argued that the generation process of Picasso's Guernica show nonmonotonic variants, because the judges' arrangement does not match the sequential order of Guernica. From his early sketches, the final product of Picasso's Guernica is hard to predict.

In contrast, Gabora (2007) argued that the Darwin's natural selection theory is not eligible for being applied to creative thought process. Gabora's argument is that the creative thought process is more like the inheritance of previous ideas which is similar to Lamarckian theory of evolution. In addition, Gabora pointed that nonmotonic process of creative idea generation does not necessarily mean that it is a Darwinian process. In other words, the fact that a given idea-generation process is non-linear does not necessarily imply that it was Darwinian process.

In Simonton's study (2007), the judges' arrangement of Guernica sketches clearly indicates a non-linear process. This non-linear process can be related with a Darwinian process; if the variants are blindly formed then the generation process of creative ideas should show some evidence of non-linear processes. Even though there could be other explanation for non-linear process, if blind-variation is the condition for novelty, then the people who generate new ideas could show non-linear ways of developing ideas.

In another study, Weisberg and Hass (2007) agreed with Simonton in terms of blindness in creative ideas. Weisberg and Hass defined blindness as the "individual's inability to predict the outcome of carrying out some operation during creative production" (p.345). Weisberg and Hass agreed that creators cannot be sure how future outcomes will turn out. However, they disagree with the possibility that free association of ideas is essential for the generation of creative thoughts. Free association is a mixture of different ideas without previous judgment that can be seen as one of the features of blind variation. They support the notion that the creative thought process is systematic process rather than a blind one.

Such arguments as this over the systematicity of one approach or the other can be applicable to the creative work of artists and scientists. However, it is still difficult to conclude that systematic approaches cannot be a Darwinian process. Experienced artists could be systematic—they have their own way of generating new ideas— toward their creative works, but this does not eliminate the possibility of free association and nonmonotonic variants.

Even though examination of the procedural sketches can reflect in some ways some evidence of the creative thought process, it does not describe the real thought process of inventors. In order to see whether the creative thought process involved is a Darwinian one, it may be examined in other ways as well. One such method is that ask questions directly to the creative thinker or inventor how they came up with their own novel ideas.

3.10 Taking Stock

The critics of the Darwinian mechanism of knowledge creation can be strengthened if they can provide more definitive evidence. The difficulty in distinguishing between genotype and phenotype in socio-economic and cognitive evolution makes evolutionary theories difficult to be tested. In other words, the definition of genotype and phenotype is not fully established in social science and this is an obstacle for examining socio-economic and cognitive evolution.

The problem of distinguishing between genotype and phenotype in creative thought processes is also challenging. Indeed, consideration about the distinction tends to bring more question than answers. When one sees the thought process that lead to a new invention, how can one distinguish between the two processes? For instance, was Edison's thought processes when he invented the light bulb more Darwinian or Lamarckian? This leads another question: do different degrees of invention (or thought process) involve different degrees of randomness? Then, there remains the need to examine the different degrees of invention and different degrees of randomness.

Even though more questions than answers are presented, the Darwinian framework should be tested if for no other reason than that it is so highly ramified in terms of policy implications for economic development. From the Darwinian point of view, the future of new ideas is unpredictable. Therefore, it is appropriate to develop systems of introducing various ideas and allow rigorous selection mechanisms to operate, regardless of the fact that this can sometimes be a highly inefficient process. From the Lamarckian point of view, the future of new ideas is predictable. Therefore, it is appropriate to develop environments that can inform new ideas.

3.11 Hypotheses

The focal hypothesis of this research is directed to determining primacy between the two approaches in evolution. Given that the received wisdom in biology is found in "the neo-Darwinian synthesis", the alternative hypothesis is the Darwinian approach and the null hypothesis is the Lamarckian approach. Even though Darwinian theory of evolution is accepted as a norm to biological scientists, it is still in doubt to general audiences around the United States. Moreover, the possibility of Lamarckian evolution has been proposed in social sciences (Nelson & Winter, 1992). The main hypothesis may be stated as follows:

H_0: The generation process of creative ideas is a Lamarckian process

H_a: The generation process of creative ideas is a Darwinian process

From this main hypothesis, the subset of hypothesis that relates specifically to inventors can be stated as follows:

H_0: Inventors will tend to ascribe to a Lamarckian view

H_a: Inventors will tend to ascribe to a Darwinian view

Since the Darwinian view is generally accepted in natural science, the null hypothesis is that inventors are more likely to support Lamarckian theory than are students. The researcher initially assumed that Darwinian theory is more plausible than Lamarckian theory for creative thinking, because the critics of Darwinian theory have not provide logical evidence to reject Darwinian theory.

If the survey data cannot reject the null hypothesis, then they imply Lamarckian theory. Even though the survey data cannot definitively test evolutionary theory, it provides some evidence indicative of either Lamarckian or Darwinian theory. If the data can reject the null hypothesis, the Darwinian theory of creative thought will remain.

Hypothesis 1

In Darwinian theory, variants are blindly generated. As we saw in chapter 3, uncertain elements in the generation process of inventive ideas can be thought of as a Darwinian process. In contrast, variants can be produced with foresight in a Lamarckian view. In other words, if the creative thought of invention is a Lamarckian process then inventors are likely to know where their inventive ideas come from. The Lamarckian theory argues that environment can instruct the living organism for developing traits. Likewise our previously stored knowledge can instruct new ideas in Lamarckian processes. Moreover, the moment that inventors come up with inventive thought needs to be specified. The generation process of new ideas needs to be broken into discrete, individually-recognizable phases instead of seeing it as a single continuous process. Usually, researchers see the whole generation process of creative ideas.

From this assumption and specification, the first set of hypotheses is as follows:

$H1_0$: Inventors will show lower level of serendipity than students in their inventive thought process

$H1_a$: Inventors will not show lower level of serendipity than students in their inventive thought process

This hypothesis can be called 'serendipity' hypothesis. If the inventors show lower level of serendipity than students then the conclusion follows that the data supports the Lamarckian theory, because Lamarckian theory argued that the development of new ideas can come from the certainty of previous knowledge and direction.

Hypothesis 2

If the inventor group shows lower level of unexpectedness than the student group, then we can say that this result supports a Lamarckian framework. In contrast, if the inventor group shows higher level of unexpectedness than the student group, then it strongly supports the Darwinian hypothesis.

$H2_0$: Inventors will show lower level of unexpectedness than students in their inventive thought process

$H2_a$: Inventors will not show lower level of unexpectedness than students in their inventive thought process

If the inventors show lower level to the question regarding unexpectedness than the students, then it can be concluded that the data supports Lamarckian theory. If the inventor group shows higher level to deliberate effort in generation of inventive ideas than the student, then it supports the Lamarckian hypothesis.

Hypothesis 3

$H3_0$: Inventors will express lower level of haphazardness than students in their inventive thought process

$H3_a$: Inventors will not express lower level of haphazardness than students in their inventive thought process

This hypothesis can be called 'haphazardness'. If the inventors show lower level of haphazardness questions than students, then we can say that the data support the Lamarckian theory because Lamarckian theory argued that the development of new ideas can come from certain directions.

Hypothesis 4

$H4_0$: Inventors will express lower level of connecting different ideas than students in their inventive thought process

$H4_a$: Inventors will not express lower level of connecting different ideas than students in their inventive thought process

This hypothesis can be called ‘divergent thinking’. If the inventors show lower level of divergent thinking than students, then we can say that the data supports the Lamarckian theory, because Darwinian theory argued that the development of new ideas can come from connecting two very different ideas together.

CHAPTER IV

METHODS AND DATA

Selection of research field. Inventors in cancer research were chosen as a focus for this project. The reason for selecting cancer research as a focus field was personal interest and curiosity. An underlying assumption is that the invention process in cancer research is not different than it is in any other fields.

4.1 Research Methods

4.1.1 Qualitative research methods

Phenomenological method. Qualitative research can in general help provide in-depth understanding of phenomena. A phenomenological approach to research in particular was used in this research for answering the first question about how inventors came up with their inventive ideas. Because this 'how' question does not readily lend itself to measurement, the researcher had to ask this question in-person. Phenomenological research involves understanding someone's experience from their viewpoint. Phenomenology focuses on the meaning of personal experiences rather than on numerical representations, and it is useful for providing in-depth understanding of personal experience (Hummel, 2006).

If we want to know about someone's experience, the best way to acquire the knowledge we seek may be by listening to their stories. Different people can have different experiences of the same phenomenon. At the same time one person's reports of their own experience may illustrate a common core of human beings who have similar experiences. For instance, we can understand the role of working women in households through their stories (Krider and Ross, 1997). In another example, the experience of parenting as a guide to children also can provide insights to others (Van Manen, 1990). Similarly, insight may be obtained through the phenomenological study of creativity using stories from artists, such as meanings of creative works and creative processes (Nelson and Rawlings, 2007).

For understanding the thought processes that catalyze invention, this project researched inventors' stories. Inventors can experience creative moments in many different ways. However, one person's story may also shed light on the inventive thought processes in ways that go beyond his or her own idiosyncrasies. In this regard face-to-face interviews are the main tool used in this research for gathering stories from inventors' experience of invention.

Justification of interview sample. The purpose of phenomenological research is to understand phenomenon. The rationale for selecting interviewees is similar to the rationale for stipulating a set of experimental conditions, or selecting a case for study. Specifically, one case would be meaningful if it can reject the conceived wisdom in terms of theoretical testing. Therefore the number of interviewees is not a critical matter, because the purpose of the interview is to understand inventors' experience of invention. Boyd (2001) regards two to ten interviews as sufficient to reach saturation in phenomenological research. Six inventors were chosen for this project.

Selection of Interviewees. The interviewee sample was a purposive sample. All were listed in the patent database as having invented something in the field of cancer research. The criteria used to select inventors were stipulated by the researcher. One inventor is a recipient of an award from the Inventor Hall of Fame in Akron, Ohio, and others are famous scholars who had been repeatedly cited by other scientists in cancer research. Additionally, geographical proximity to the researcher was considered as well.

Profiles of Interviewees

Ian Cheong: Cheong studied law as an undergraduate student in Singapore. After graduation he worked for a law firm. While he was in the law firm, he had a chance to see interesting things in patent applications. This experience stirred his mind and led him to science. He went back to college and studied biology.

During his studies in biology he worked with a mentor who had worked with Johns Hopkins University. Cheong came to Johns Hopkins after finishing his course in Singapore. Cheong was in a cancer lab and had the chance to work with what his predecessor had studied. The subject is bacterium that is sensitive to oxygen.

One day when he was thinking about this bacterium, a breakthrough idea came to his mind. The idea was that this bacterium might be used as an element in a cancer drug. The process, he thought, might go something like this. First, the bacteria will be injected to the human then these bacteria will be located on tumors which have plenty of oxygen relative to other cells. Second, the cancer drug will be injected and will affect only those tumors since the bacteria reside with tumors. Cheong received an award from the Inventors Hall of Fame for this breakthrough.

George Stark. Stark invented a way to attack mammalian cells. His lab is famous for developing novel ways to identify mechanisms between proteins and interferon important for cancer research. Stark's lab produces proteins that are used in labs around the world.

Robert Silverman. Silverman and his colleagues have studied how human protein resists viruses. They studied the genes that would be responsible for immunity against some virus infections. In 2002 team of cancer geneticists in other institution mapped a prostate cancer gene to the same gene that the Silverman's lab had been working on for many years. With these developments, Silverman proposed a bacteria hypothesis in prostate cancer that had not previously been considered as a possible cause.

Alexandru Almasan. Almasan's lab studies the molecular basis of apoptosis and cell cycle control regulation. He and his associates made an interesting observation about an important protein known to have a function in cell cycle regulation; specifically that it dramatically modified cell function. Their discovery put Cyclin-E on a completely different task because this modified protein is related with cell death. Before it had been known that Cyclin-E is important for cell proliferation; Almasan also discovered that it can be important for cell death.

Clemencia Colmenares. Colmenares studied the transcriptional control of gene expression during development of embryos. Her lab uses mice that are lacking the so-called Ski oncoprotein, which is associated with cancer cells. This oncoprotein is also linked with human microdeltion syndrome that affect defects of human face. Colmenares is working on indentifying the specific genes that are associated with facial clefting in humans.

Carlo Croce. Croce speculated that he could isolate cancer genes by destroying some specific chromosomal alterations. And this speculation turned out to be quite exciting because it enables one to clone and identify oncogenes so that other people can clone and identity many more of the onoogene.

Interview. The first research question in this project is: *how do inventors come up with their inventive ideas*? This question can be addressed in part by a qualitative method such as an interview. The rationale behind using an interview is not similar to the rationale behind using a probability sample, in that the point is to generalize statistically to the population. Rather the point is to understand the interpretation of invention in terms of the lived experience of inventors. More specifically, from inventors' stories the researcher in this case sought to discern whether their experiences of invention exhibit the characteristics of Darwinian creative thought processes or not. The process of analyzing interview results can be summarized in three phases: description of responses, reduction of responses, and interpretation of responses (Krider & Ross, 1997).

From the inventors' descriptions of the process of getting new ideas, one can interpret the meanings of the generation process of new ideas. The interview process did not specify the two viewpoints of the generation process of inventive ideas, because such specification might have influenced the interviewees to identify with a specific framework. The main questions of the interview were as follows: *Can you tell me about your creative work? Can you tell me about how you came up with creative ideas? What were the important factors in your experience of invention? What are the obstacles for* *your invention?* The protocol of questions is attached in appendix A. The interviews were recorded by a recording device. The recorded interviews were transcribed after completion by the researcher and professional service agency. From these transcriptions, the main themes and patterns were analyzed and interpreted by the researcher.

The transcribed expressions were reviewed by the researcher. The researcher tried to find out any patterns or themes from their responses. In particular, the researcher focused on any indication of the two theories from their responses. After this process, the researcher classified the similar responses into themes. For instance, one of the themes from the interview was 'I stumbled upon the solution.' This theme came from the responses of the inventors who said the solution to their problem was not expected. Moreover, the words in the inventors' responses were also used in survey items to reflect inventive thought processes.

4.1.2 Quantitative method

Survey design. The second purpose of this project is to compare Darwinian with Lamarckian theory in terms of creative thought processes. In order to this, the researcher developed a set of survey items administered on a questionnaire. The questionnaires were developed on the basis of information obtained from the aforementioned literature on the two evolutionary theories, as well as on the basis of information obtained from the interviews. For instance, the first interviewee mentioned that his discovery of the drug delivering method was experienced as being a more-or-less random process. This can be viewed as indicative of a Darwinian thought process. Such statements made by inventors provided the basis for some of the survey items. Moreover, the two evolutionary theories provided constructs and items regarding the Darwinian approach (Campbell, 1960;

Perkins, 1997; Simonton, 1999a; Hodgson and Knudsen, 2006) and the Lamarckian approach (Sternberg, 1998; Dasgupta, 2004; Weisberg, 2006; Gabora, 2007).

Survey sample. Two groups of people were selected for this project, inventors and students. The inventors are people who developed significant ideas in cancer research; they were selected to represent people who develop new and creative ideas. Each inventor has an invention that has been successfully evaluated and legitimized by the patent system. The students who comprised the comparison group were selected to represent ordinary people who had not demonstrated success at creative thinking, as had the patent holders. The students did not yet contribute to the advancement of scientific knowledge. The purpose of two groups was to compare the responses from characteristically different sorts of individuals in terms of similar questionnaire items.

The inventor group is comprised of patentees who registered patent(s)[3] in cancer research from 2007 to May 2009. From these patents, patents that have 'cancer' in abstract were selected for identifying patentees with inventions related to the field of cancer research. From selected inventors in cancer research, inventors in universities are selected in order to increase response rate since the researchers at university are less frequently moved to another institution than researchers at private companies. The inventor sample is made up of inventors in cancer research who were affiliated with a university.

[3] There is debate about using patent data as a representation of invention because there are many different kinds of patents. This project does not support the idea that patents in general are proxies for an invention. Patent data can be seen as both invention and innovation. The project assumed that patents in cancer research had both properties of invention and innovation.

A total of 500 surveys were mailed-out to inventors in universities who have at least one patent in cancer research. The assumption is that inventors in universities may be not so different from inventors in companies.

To compare the inventor group with a group of non-inventors, a group of students was drawn. Asking similar questions to a comparison group highlights the differences between their thought processes or the different degree of thought processes between two groups. A convenience sample of students at Cleveland State University served as a comparison group.

Survey: The basic idea of the questionnaire instrument is from Hadamard's study (1945) that examined mathematicians' thought process in their problem solving. For instance, Hadamard asked open questions to mathematicians as follows: "What, in your estimation, is the role played by chance or inspiration in mathematical discoveries?" (Hadamard, 1945, p.138). In this case, rather than asking about math, the researcher developed set of hypotheses related to the two evolutionary theories. These theories informed the items used for testing the two theories. The full survey instrument is attached in the appendix B.

Survey items

Dependent variables: From Darwinian theory, the following characteristic constructs can be specified: 'unexpectedness', 'serendipity', 'trial-and-error', 'connecting different ideas', and 'random-generation and knowledge-selection.' On the other hand, Lamarckian theory leads to the opposite constructs of 'extension from knowledge' and 'predictability.' The variables analyzed are comprised of the responses by the respondents from the two groups to these constructs. Each construct is represented by one or more items on the survey.

Independent variable: There were two groups of subjects in this project. The first group was made up of inventors who have been issued a patent(s) in cancer research. Inventors were chosen because they represent people who have demonstrated that they generate significant creative ideas. The second group is made up of students who have not been issued a patent(s).

The major parts of the survey can be divided into two theories in evolution.

Darwinian theory

Unexpectedness: In Darwinian theory blind variation is related with unexpectedness of creative ideas. Unexpectedness includes the expressions, such as 'a-ha moment', 'unexpected discovery', 'without any clue', 'did not expect', and 'no-intention' in survey items.

1. I have experienced an 'A-ha' moment in which a creative idea happened unexpectedly.

7. Sometimes a creative idea comes to my mind at a very unexpected time when I am not really trying to think about solving the problem to which the idea applies.

8. In my experience, the essential part of generating a creative idea has come from unexpected discovery rather than advanced planning.

11. The essence of a new and inventive idea is found in unexpected discovery.

16. Creative ideas strike my mind without any advance indication or clue.

18. Usually I have had a creative idea that has come to my mind when I was not trying to think of it.

19. When I started my project I did not expect to end up with the creative ideas that I discovered.

24. Sometimes I have ended up coming up with a creative idea that applied in a problem that at first I had no intention of working with.

If inventors agree with these items, then we can say that creative thought process is more likely Darwinian process.

Serendipity: Blind variation can make creative thought process close to serendipitous moment. Therefore the expression of 'serendipitous' and 'chance' in the survey item was used for operationalizing serendipity.

4. In my experience the generation of creative ideas is a serendipitous process, so I do not know for sure how creative ideas have occurred to me.

13. My experience is that the generation of creative ideas is a serendipitous process that seems to happen almost completely by chance.

23. More substantial and significant discoveries involve a greater element of chance.

If inventors agree with these items, then we can say that creative thought process is more likely Darwinian process.

Trail-and-error: Trial-and-error can be the core of blind-variation-and-selective-retention model. 'Trial-and-error' and 'lots of useless ideas' were used for operationaliztion.

3. In my experience, creative thought processes amount to trial-and-error for coming up with new ideas.

6. Before coming up with a creative idea that actually worked in application, I first considered lots of other ideas, though most of them proved to be useless.

15. When I have been faced with coming up with new ideas in problem situations I have never encountered before, I have tended to respond to the situations based upon trial-and-error.

If inventors agree that they produced lots of useless ideas and trial-and-error, it could be lead to thought process is related with Darwinian theory.

Connecting different ideas: This concept is operationalized by using 'free association', 'connecting two different ideas', and 'collecting bunch of ideas.'

12. In my experience, the free association of haphazard ideas is a first step toward coming up with new ideas.

21. I have tended to come up with new and creative ideas by connecting two or more other, very different ideas together.

22. My creative ideas have often started with collecting a bunch of information followed by making connections at what seems to be a subconscious level.

If inventors agree with these items, then we can say that creative thought process is more likely Darwinian process.

Random-generation and knowledge-selection: This is operationalized by 'come up with ideas unintentionally' and 'use acquired knowledge to select amongst them.'

5. In coming up with creative ideas I have come up with trial ideas unintentionally, but have used my previously acquired knowledge to test and select amongst them.

If inventors agree with this item, then we can say that creative thought process is more likely Darwinian process.

Lamarckian theory

Extension from previous knowledge: It is operationalized by 'informed from previous knowledge' and 'caused primarily from facts, events, and circumstances outside of my own mind.'

2. My creative ideas have been informed from my previous knowledge.

10. My creative ideas have been caused primarily from facts, events, and circumstances outside of my own mind.

20. My creative ideas have always been direct extensions of my previous knowledge.

If inventors agree with these items, then we can say that creative thought process is more likely Lamarckian process.

Predictability: Predictability is operationalized by using 'deliberate effort', 'predictable sequences of thought', and 'I have known immediately.'

9. I can predict that my creative ideas will be generated by deliberate effort and hard work.

14. I have generated creative ideas through clear and predictable sequences of thought.

17. When I have come up with a creative idea I have known immediately whether or not the idea would prove to be successful.

If inventors agree with these items, then we can say that creative thought process is more likely Lamarckian process.

Pilot Test: Once the survey items were developed, the researcher performed a pilot test of the survey using 10 doctoral students in the Maxine Goodman Levin College of Urban Affairs. The reason for selecting doctoral students is that they seemed more likely to have experienced creative moments than undergraduate or master level students, since they are required to produce novel ideas and hypotheses during their doctoral dissertations. The purpose of the pilot test was to examine the flow of questionnaires, the possibility of errors, and dimensionality.

Survey process: Once the pilot test was completed, the survey was sent out to the inventors by mail. The return envelop was included in the original survey package. A total of 500 survey packages were sent out and the researcher expected a 10% response rate such as is generally accepted for a mail-out survey. A total of 53 responses were received (10.6%).

For the student group, the researcher went to the classroom and distributed the survey questionnaires. Total of 118 students' surveys are collected. The researcher went to the classrooms in the Levin College of Urban Affairs at Cleveland State University. Before doing the classroom survey the researcher asked to the instructor for permission. The researcher explained about survey and the students filled out the questionnaires within 15 minutes.

4.2 Analysis Method

MANOVA and ANOVA were used to analyze the survey data. MANOVA was used when there are multiple dependent variables and categorical independent variables. This project has multiple dependent variables that are related to two theories. The independent variable is either an inventor or a student. The main purpose of MANOVA was to test whether the two groups were different when considering dependent variables together. When the MANOVA results were significant, ANOVA was performed to examine which variable is significantly different for two groups.

Multivariate Analysis of Variance (MANOVA). Multiple Analysis of Variance (MANOVA) was utilized to analyze the overall survey data. MANOVA was used when there are multiple dependent variables and one categorical independent variable. Reasons for using MANOVA were two fold: 1) to examine mean differences on multiple dependent variables; 2) to examine the relationship among variables. Moreover, MANOVA analysis determines a linear combination of variables that maximizes group differences (Bray & Maxwell, 1985).

The multivariate test presents the simultaneous test for group difference (inventors and students) with dependent variables. These statistics consider both the between groups' difference and also the relationship among dependent variables (Bray & Maxwell, 1985).

The main hypothesis of the project is that the student and inventor groups are different in their perspectives regarding their views of for the process of generating creative ideas. The survey items ask about their thought processes of creative ideas.

CHAPTER V

RESULTS

5.1 Qualitative Results[4]

Stumbled into the solution. The first theme that the researcher recognized and expected from inventors' stories had to do with reports of an 'unexpected' element in their inventive thought process. The psychological and evolutionary theories indicate that if inventive thought processes are Darwinian, the inventor will have and experience some unexpected elements within his or her creative thought processes.

After studying Law, Ian Cheong started to have interest in science during the period when he worked for the law firm. He quit his job in the law firm and went back to college to study biology. After taking courses in biology, Cheong had a chance to work in a cancer research center at Johns Hopkins University. While he worked in this center, Cheong received an award from 'Inventor Hall of Fame' for his breakthrough in the delivery method for applying cancer drugs to tumors only. In comparison to previous

[4] The quotations of the interview are provided literally. Some of the transcription was done by professional service.

delivery methods, Cheong's invention is highly effective and the method is far less harmful for healthy cells (personal communication, 2008).

His inventive process began with the study of a bacterium that is sensitive to oxygen. One of the known features of the bacterium is that it can burst blood cells. The inventive idea of replacing the blood cell with a drug capsule came to his mind when he was walking around the corridor between his lab and the kitchen area at work. Cheong described the moment of having a new idea as the idea 'struck' him. Instead of deliberately searching for an answer, the original idea came to Cheong's mind suddenly, and at an unexpected time.

> Solution for this came before. I didn't think it was very problem because I didn't read enough of it. But I stumbled into the solution before I knew the problem is real problem. So that is how it hit me. I was thinking about this I was looking at the plate. It was struck me that we don't have to stick with this. Let's make the bug actually do something useful with it. This is useless property. I mean it burst blood cells. It does not help anyone. But if we could have it burst something else that use drug instead of bursting red blood cell, not hemoglobin, this will be pretty awesome. So it was just a 'random' idea and I did not know it could be done (personal communication, 2008).

Cheong's expression revealed the unexpected moment of his discovery. Previous studies showed the property of this bacterium that it is sensitive to oxygen and has the ability to burst blood cells. This bacterium can be put into patients and will be attracted to and reside within cancerous tumors, not healthy cells. The new idea is to replace the naturally occurring blood cell with an artificial cell that contains the cancer drug. Therefore, the bacteria now can burst the cell using the cancer drug. And when the cancer drug is injected to the patient, the drug only affects tumor cells like 'delivering pizza to the right addresses.'

Cheong referred to the new idea as a "random" idea. He did not consider the problem of cancer drugs that kill healthy cells, when he came up with this new idea. His discovery happened before he conceptualized the problem of cancer drugs. As Cheong said he did not know how this discovery could be done in advance. He clearly did not expect that he would have a moment of generating a new idea.

Another interview revealed another example of unexpectedness in the inventive thought process. When asked about the thought process of invention, Stark put his experience of invention as a 'subconscious' thought activity as follows:

> Ideas come in variety of ways and part of it I've never been really interested in my own thought processes. Very often an inventive idea comes from when you are not trying to think of it. So you know, you get up in the morning and you're taking a shower and stuff is running through your head and almost at a subconscious level all of sudden you know "oh" and a realization happens that maybe you can think about in new way (personal communication, 2009).

Stark described his thought process as occurring at an "almost subconscious" level, as he did not realize how the new idea came to his mind. This expression again confirms the presence of the property of unexpectedness in inventive thought processes.

The researcher interviewed Robert Silverman who has a patent on a technology for prostate cancer. During his career in biomedical research, Silverman was able to hypothesize that a bacterium may cause prostate cancer. He described his experience of invention as "unexpected" due to the fact that he accidentally found his way to this research project.

> We actually did not start out looking for this virus. Rather, we had a long path to the discovery footsteps. When scientists start at one place we never know where you're going to end up. 'We follow our discoveries.' One discovery leads to another discovery (personal communication, 2009).

Silverman's experience involved discoveries that led to unexpected outcomes and research projects. Originally, he studied how infection invades human cells, but his journey ended up at this juncture investigating the viral hypothesis of prostate cancer. These outcomes in scientific research indicate that there are at times elements of unexpectedness and uncertainty involved in scientific research and invention.

Like raising your arm. Another emerging theme from these inventors' stories is that invention needs two parts: knowledge and creativity. Inventors must have prior knowledge about their field and at the same time, the invention process requires creativity in order to see the problem in different ways. Cheong emphasized that relaxation is critical to creativity:

> I think you have to loosen the mind little bit. The thought process is like raising the arm. One muscle must contract while one muscle must loosen. Creativity is a very delicate process of generation. It is like a forgiving process (personal communication, 2008).

As Cheong expressed his 'raising arm' metaphor, the invention process needs extra effort to loosen up the existing rules and ideas. Getting the background information and knowledge focused upon the problem or situation can be seen as analogous to the contraction of muscles, and creativity can be seen as analogous to the relaxation of muscles.

In similar way, Stark said that the creative thought process needs background information, and that some part of the generation of creative ideas cannot be controlled by him.

> The idea is you have to have background information. Part of it is an active process. You really need to be focused on trying to work on this problem and to obtain facts and to think about it. But sometimes a good solution comes to you out of an unexpected time, when you do not really try to think about it. It makes me wonder about how much control we really have at a conscious level in terms of the inventive process in our mind. I think you need to be prepared; you need to have information; you need to have willingness you want to try something; but sometimes the solution comes in a very subconscious way. It is interesting phenomenon (personal communication, 2009).

Stark explained that an individual needs to have knowledge and make effort to generate an invention. However, knowledge and effort are not the sole contributions to successful inventive thought processes. Rather, inventive ideas can come in an unexpected way. We have limited control of our own thought processes. Therefore, preparedness and a notable degree of personal freedom or liberty need to be available for the person generating creative ideas.

Croce expressed his views about the importance of imagination in addition to knowledge as follows: "Imagination is some talent that you have or you don't have in that you to make that interesting discovery because if you just based everything about whatever else will stand out is done by others." (personal communication, 2009)

Tried different things and one worked. The third theme from the inventors' experience is that they tried different things for the solution. This is also linked with the second theme which is about knowledge and creativity and how they are used to solve difficult problems by handling them in different ways to reach the solution (Campbell, 1960). Stark stated that his team of scientists tried different alternatives and found out the solution as follows: "I don't know how to describe it all. We had several different ideas. And finally we tried different things. One of them finally worked" (personal communication, 2009).

It is difficult to come up with new ideas for problems especially when the problems have not been encountered before or the solution for the problem is not developed yet. Therefore, different ideas are tested to seek for alternative options for addressing the problem. The underlying assumption of these trials of ideas is that we do not know which one from the various ideas will eventually be the solution.

Beinhocker (2006) supported this 'trying many different things' theme by summarizing as follows:

> In effect, evolution says, "I will try lots of things and see what works and do more of what works and less of what doesn't." But in this process of sifting, remarkable things happen. This algorithm learns what the fitness function "wants," knowledge of that learning accumulates in the population of schemata, and the evolutionary process generates novelty as it searches for fitter and fitter designs (p. 216).

Open to variety. During the interviews, after having been asked about the helpful things to invention, Cheong replied that having interest in many things is important to creativity. Cheong said that "One thing maybe prepares the mind and then the moment will happen. Connecting two things can create something new. I would say be interested in many things. It does not mean to not be focused. Nothing is ever wasted" (personal communication, 2008). As Cheong articulated the point, focused interest is important for coming up with new ideas. However, Cheong also accentuated that a wide range of interest also can be useful for coming up with new ideas. Cheong's view indicated that such interest may be learned. Cheong studied law before he entered in to the biomedical field. From Cheong's reports of his experience, inventive ideas can also come from the connection of two very different things.

Possibility of error. Silverman replied with his emphasis on openness to the possibility of error as a primary condition for scientific research.

> You have to be open minded. You cannot be too stuck on with just one idea, because that means you could be wrong. And you kind of have to go with research leads you which is difficult. It is difficult to give up hypothesis that you working on. You have to be open minded (personal communication, 2009).

Silverman's argument was that science can have different hypothesis each of which contains the possibility of error. Therefore, scientists should open their mind to different hypotheses. In his view, any given theory is not the definitive truth about the phenomenon but rather is one feasible explanation based on evidence in the current time and situation. In many cases, the hypothesis can be wrong and changing hypotheses can lead to different and new ideas.

Extension from previous knowledge. The last theme in the interview data is that inventive ideas are extended from previous ideas. This theme can be viewed as an opposite of a defining feature of Darwinian (as opposed to Lamarckian) theory because it emphasizes previous literature and knowledge. Even though previous knowledge is important for both Darwinian and Lamarckian theory, Lamarckian theory emphasizes the role of previous ideas in that it posits that creative ideas are mere recombinations or extensions of old ideas, rather than completely new emergent phenomena. In contrast, Darwinian theory places more emphasis upon the unpredictability of discovery. Colmenares expressed her research experience as follows:

> And that's where I found these birth defects in the mice that are similar to the birth defects that humans get frequently. But – so, a lot of these ideas come from reading and/or hearing what other scientists do (personnel communication, 2009).

Colmenares' response in this regard is closer to Lamarckian theory, since her idea came from reading and listening to other scientists. Various sources of information form the base for new ideas, however, the way of new ideas are generated is the matter. Even though she did not mention anything about deterministic patterns in her research, her response highlights logical reasoning more consistent with a Lamarckian approach.

5.2 Quantitative Results

Sample Statistics. The survey analysis is based on total of 171 responses, including 118 student responses (69%), and 53 inventors (31%). There were 78 female respondents (46%) and 93 males (54%). The average age of the respondents was 38 years old. Cronbach's alpha is 0.68 which is close to conclude that the survey item is reliable to measure one dimension.

With respect to the students group, all were from the Maxine Goodman College of Urban Affairs in Cleveland State University. There were 68 female students (58%) and 50 male students (42%). Average age for the student group was 32 years old.

A total of 53 out of 500 mail-out surveys were returned from the inventor sample, making the response rate about 10.6%. Of these, ten were females (20%) and 41 were males (80%). The average age for the respondents in the inventor group was 52 years old.

Table 2

Descriptive Statistics

Items	Mean	Std. Deviation	Variance
Q1	4.360	0.765	0.585
RQ2*	1.778	0.846	0.715
Q3	3.490	0.918	0.843
Q4	2.850	1.012	1.024
Q5	3.760	0.823	0.678
Q6	3.220	1.033	1.068
Q7	4.120	0.987	0.974
Q8	3.500	1.001	1.001
RQ9	2.935	1.050	1.102
RQ10	3.065	0.911	0.830

Q11	3.510	0.872	0.760
Q12	3.400	0.949	0.900
Q13	2.760	1.015	1.030
RQ14	2.480	0.941	0.886
Q15	3.180	0.956	0.914
Q16	3.400	1.085	1.176
RQ17	3.216	1.054	1.112
Q18	3.400	1.076	1.159
Q19	3.380	1.001	1.002
RQ20	2.684	1.026	1.053
Q21	3.780	0.832	0.692
Q22	3.730	0.875	0.765
Q23	3.070	1.027	1.054
Q24	3.700	0.798	0.636

*RQ means that original data are recoded.

Table 2 shows descriptive statistics for each question. Original data has been re-coded according to the nature of questionnaire in order to have same meaning. For instance, if somebody answer question #2 with strong agreement(5 in response), it is recoded to 1. Because the question #2 is based on Lamarckian theory, the response is recoded for having same direction with Darwinian responses. All questionnaires from Lamarckian theory are recoded same way. After recoding high scores mean that the responses are closer to Darwinian theory and low scores mean that the responses are closer to Lamarckian theory. The highest mean is 4.36 in question #1. The standard deviation is between 0.765 in question #1 and 1.085 in question #16.

Factor analysis

After having survey data, factor analysis is run for grouping items. Eight factors are drawn using correlation matrix and varimax rotating.

Table 3

Total Variance Explained

	Initial Eigenvalues			Rotation Sums of Squared Loadi		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulativ
1	4.138	17.241	17.241	2.832	11.801	1
2	2.564	10.682	27.923	2.068	8.615	2
3	1.753	7.303	35.226	1.963	8.181	2
4	1.581	6.586	41.811	1.853	7.721	3
5	1.335	5.562	47.374	1.589	6.619	4
6	1.195	4.98	52.353	1.579	6.578	4
7	1.182	4.923	57.277	1.539	6.414	
8	1.065	4.44	61.716	1.389	5.786	6

Table 3 shows eigenvalues of factors and how much variance are explained by factors. Eigenwales, scree plot and variance explained led to eight factors. These factors explain about 62% of variance.

Table 4

Factors and items

Factors	Items
Away from problem	18. Usually I have had a creative idea that has come to my mind when I was not trying to think of it. 7. Sometimes a creative idea comes to my mind at a very unexpected time when I am not really trying to think about solving the problem to which the idea applies. 16. Creative ideas strike my mind without any advance indication or clue.
Unexpectedness	19. When I started my project I did not expect to end up with the creative ideas that I discovered. 23. More substantial and significant discoveries involve a greater element of chance. 11. The essence of a new and inventive idea is found in unexpected discovery. 8. In my experience, the essential part of generating a creative idea has come from unexpected discovery rather than advanced planning.
Direct extension of knowledge	2. My creative ideas have been informed from my previous knowledge. 21. I have tended to come up with new and creative ideas by connecting two or more other, very different ideas together.
Trial-and-error	15. When I have been faced with coming up with new ideas in problem situations I have never encountered before, I have tended to respond to the situations based upon trial-and-error. 3. In my experience, creative thought processes amount to trial-and-error for coming up with new ideas. 6. Before coming up with a creative idea that actually worked in application, I first considered lots of other ideas, though most of them proved to be useless. 17. When I have come up with a creative idea I have known immediately whether or not the idea would prove to be successful.
Hard work with external cause	9. I can predict that my creative ideas will be generated by deliberate effort and hard work. 14. I have generated creative ideas through clear and predictable sequences of thought. 10. My creative ideas have been caused primarily from facts, events, and circumstances outside of my own mind.

Serendipity	4. In my experience the generation of creative ideas is a serendipitous process, so I do not know for sure how creativ ideas have occurred to me. 13. My experience is that the generation of creative ideas is serendipitous process that seems to happen almost complete by chance.
No intention	24. Sometimes I have ended up coming up with a creative ic that applied in a problem that at first I had no intention of working with 20. My creative ideas have always been direct extensions of my previous knowledge. 5. In coming up with creative ideas I have come up with tria ideas unintentionally, but have used my previously acquired knowledge to test and select amongst them 1. I have experienced an 'A-ha' moment in which a creative idea happened unexpectedly.
Free association	12. In my experience, the free association of haphazard idea is a first step toward coming up with new ideas. 22. My creative ideas have often started with collecting a bunch of information followed by making connections at wh seems to be a subconscious level.

Table 4 presents each factors and items. Rotated factor loading matrix (Appendix E) is used for this grouping. However, one item (Q 20) has cross relationship with other factor as well. First factor is named 'away from problem.' Three items are related with first factor. Third factor is called 'direct extension of knowledge', because the item expressed that the new ideas are informed through previous knowledge rather than different ideas and approaches.

MANOVA

Table 5

Multivariate Tests of Inventors with the Dependent Variables

Tests	Value	F	Hypothesis df	Error df	Sig.
Pillai's Trace	0.242	6.195	8	155	0
Wilks' Lambda	0.758	6.195	8	155	0
Hotelling's Trace	0.32	6.195	8	155	0
Roy's Largest Root	0.32	6.195	8	155	0

All four tests show significant results ($p<0.01$). This multivariate test result shows that there are differences between inventors and students when the dependent variables are considered simultaneously. Factor scores are used for dependent variables and two groups are used for independent variable.

Analysis of Combined Items

Table 6

ANOVA Results for Factor Scores

		Sum of Squares	df	Mean Square	F	Sig.	Student factor score
Factor score 1	Between Groups	8.053	1	8.053	8.419	0.004	0.145
Away from problem	Within Groups	154.947	162	0.956			
Factor score 2	Between Groups	1.004	1	1.004	1.004	0.318	-0.051
Unexpectedness	Within Groups	161.996	162	1			
Factor score 3	Between Groups	13.555	1	13.555	14.694	0	0.188
Direct extension of knowledge	Within Groups	149.445	162	0.923			
Factor score 4	Between Groups	0.201	1	0.201	0.2	0.655	0.023
Trial-and-error	Within Groups	162.799	162	1.005			
Factor score 5	Between Groups	0.371	1	0.371	0.37	0.544	0.031
Hard work with external cause	Within Groups	162.629	162	1.004			
Factor score 6	Between Groups	9.671	1	9.671	10.218	0.002	0.159
Serendipity	Within Groups	153.329	162	0.946			
Factor score 7	Between Groups	0.648	1	0.648	0.646	0.423	-0.041
No intention	Within Groups	162.352	162	1.002			
Factor score 8	Between Groups	5.988	1	5.988	6.178	0.014	0.125
Free association	Within Groups	157.012	162	0.969			

Table 6 shows ANOVA results using factor scores. Four factors out of eight are statistically significant. Student group has higher mean factor scores than inventor group. Three factors(away from problem, serendipity, free association) are linked with Darwinian framework, and one factor(direct extension of knowledge) is associated with Lamarckian theory.

Item Level Analysis

Analysis of Variance (ANOVA). From the MANOVA tests, the researcher found that there is group difference between the inventors and the students in terms of their views of the creative thought process. More specifically, there are differences between groups in terms of their view of the degree to which creative thought processes are Darwinian or Lamarckian. Thus, ANOVA was used to examine the individual items that contribute to the difference between the two groups.

Table 7

ANOVA Results

		Sum of Squares	df	Mean Square	F	Sig	Student mean	Inven mean
Q1	Between Groups	0.283	1	0.283	0.482	0.489	4.390	4.3
	Within Groups	99.238	169	0.587				
RQ2	Between Groups	13.502	1	13.502	21.118	0.000	1.966	1.3
	Within Groups	108.053	169	0.639				
Q3	Between Groups	0.039	1	0.039	0.046	0.831	3.500	3.4
	Within Groups	142.455	168	0.848				
RQ4	Between Groups	9.810	1	9.810	10.094	0.002	3.010	2.4
	Within Groups	164.237	169	0.972				
Q5	Between Groups	0.086	1	0.086	0.127	0.722	3.780	3.7
	Within Groups	114.502	168	0.682				
Q6	Between Groups	0.135	1	0.135	0.126	0.723	3.200	3.2

	Within Groups	181.421	169	1.073				
Q7	Between Groups	3.429	1	3.429	3.572	0.060	4.210	3.9
	Within Groups	162.232	169	0.960				
Q8	Between Groups	0.051	1	0.051	0.051	0.822	3.510	3.4
	Within Groups	168.197	167	1.007				
RQ9	Between Groups	3.751	1	3.751	3.452	0.065	3.034	2.7
	Within Groups	182.537	168	1.087				
RQ10	Between Groups	1.571	1	1.571	1.903	0.170	3.000	3.2
	Within Groups	138.717	168	0.826				
Q11	Between Groups	0.003	1	0.003	0.003	0.954	3.510	3.5
	Within Groups	128.492	168	0.765				
Q12	Between Groups	12.146	1	12.146	14.577	0.000	3.580	3.0
	Within Groups	140.814	169	0.833				
Q13	Between Groups	18.902	1	18.902	20.442	0.000	2.980	2.2
	Within Groups	156.268	169	0.925				
RQ14	Between Groups	1.503	1	1.503	1.703	0.194	2.542	2.3
	Within Groups	149.175	169	0.883				
Q15	Between Groups	0.860	1	0.860	0.941	0.334	3.230	3.0
	Within Groups	154.520	169	0.914				
Q16	Between Groups	2.852	1	2.852	2.445	0.120	3.490	3.2
	Within Groups	195.948	168	1.166				
RQ17	Between Groups	0.175	1	0.175	0.157	0.693	3.195	3.2
	Within Groups	188.819	169	1.117				
Q18	Between Groups	23.116	1	23.116	22.472	0.000	3.640	2.8
	Within Groups	173.843	169	1.029				
Q19	Between Groups	0.271	1	0.271	0.269	0.605	3.410	3.3
	Within Groups	170.022	169	1.006				
RQ20	Between Groups	1.073	1	1.073	1.019	0.314	2.737	2.5
	Within Groups	177.875	169	1.053				
Q21	Between Groups	12.968	1	12.968	20.954	0.000	3.590	4.1
	Within Groups	104.588	169	0.619				
Q22	Between Groups	0.180	1	0.180	0.234	0.629	3.700	3.7
	Within Groups	129.902	169	0.769				
Q23	Between Groups	0.142	1	0.142	0.134	0.715	3.050	3.1
	Within Groups	179.016	169	1.059				
Q24	Between Groups	0.123	1	0.123	0.192	0.662	3.680	3.7
	Within Groups	108.065	169	0.639				

Table 7 presents ANOVA results for all variables. Six variables out of twenty-four variables are significant in terms of statistical significance for difference of group means

Group means of eighteen variables are not significant in terms of statistics. It is difficult to draw any conclusion from these eighteen items. The possible reason could be items were not clear enough to be distinguished between two groups.

Table 8

Significant ANOVA Group Mean

		Sum of Squares	df	Mean Square	F	Sig.	student mean	inventor mean
RQ2	Between Groups	13.502	1	13.502	21.118	0.000	1.966	1.359
	Within Groups	108.053	169	0.639				
RQ4	Between Groups	9.810	1	9.810	10.094	0.002	3.010	2.490
	Within Groups	164.237	169	0.972				
Q12	Between Groups	12.146	1	12.146	14.577	0.000	3.580	3.000
	Within Groups	140.814	169	0.833				
Q13	Between Groups	18.902	1	18.902	20.442	0.000	2.980	2.260
	Within Groups	156.268	169	0.925				
Q18	Between Groups	23.116	1	23.116	22.472	0.000	3.640	2.850
	Within Groups	173.843	169	1.029				
Q21	Between Groups	12.968	1	12.968	20.954	0.000	3.590	4.190
	Within Groups	104.588	169	0.619				

Table 8 represents significant items in terms of differences of group mean. These items' means are meaningfully different due to variance between groups. Six items out of 24 items are significantly different by groups. With the exception of item #21, the student group shows higher mean than the inventor group, which means the student group is more supportive of Darwinian view than the inventor group.

Research Hypothesis 1

$H1_0$: Inventors will show lower level of serendipity than students in their inventive thought process

$H1_a$: Inventors will not show lower level of serendipity than students in their inventive thought process

Sixth factor is linked with two items, item #4 'In my experience the generation of creative ideas is a serendipitous process, so I do not know for sure how creative ideas have occurred to me' and item #13 'My experience is that the generation of creative ideas is a serendipitous process that seems to happen almost completely by chance' were designed to measure the 'serendipity.' From the viewpoint of Darwinian evolution, serendipity can be seen as a characteristic indicative of blind-variation. Therefore these item can be seen as support for Darwinian theory, if the subject agree with the statement. The students' mean factor score is 0.159 and inventors' mean is -0.372. Thus, we can say that the inventors are less supportive of the Darwinian view than the students.

Research Hypothesis 2

$H2_0$: Inventors will show lower level of unexpectedness than students in their inventive thought process

$H2_a$: Inventors will not show lower level of unexpectedness than students in their inventive thought process

First factor is related with three items, item #18 'Usually I have had a creative idea that has come to my mind when I was not trying to think of it', item #16

'Creative ideas strike my mind without any advance indication or clue', and item #7 'Sometimes a creative idea comes to my mind at a very unexpected time when I am not really trying to think about solving the problem to which the idea applies.'

The items were designed to measure the 'unexpectedness.' This has been re-named to 'away from problem' after factor analysis. From the Darwinian theory, the presence of unexpectedness is indicative of blind-variation. Therefore when a subject agrees with this item, it can be seen as supportive of Darwinian theory. The students' mean factor socre is 0.145 and inventors' mean factor score is -0.339. Thus, the students are relatively more supportive of Darwinian perspective than the inventors.

Research Hypothesis 3

$H3_0$: Inventors will express lower level of haphazardness than students in their inventive thought process

$H3_a$: Inventors will not express lower level of haphazardness than students in their inventive thought process

Third factor is related with two items, item #2 'My creative ideas have been informed from my previous knowledge'and item #21 '21. I have tended to come up with new and creative ideas by connecting two or more other, very different ideas together.' These items were designed to measure the 'instruction.' From the Lamarckian theory the extension from previous knowledge can be seen as more direct process than unexpectedness of Darwinian theory. Therefore if the subject agrees with the statement, this item can be seen as support for Lamarckian theory. The students' mean factor score is 0.188and inventors' mean factor score is -0.440. We can thus conclude that the students are more supportive of Lamarckian views in comparison to the inventors.

Research Hypothesis 4

$H4_0$: Inventors will express lower level of connecting different ideas than students in their inventive thought process

$H4_a$: Inventors will not express lower level of connecting different ideas than students in their inventive thought process

Eighth factor is related with two items, item #12 'In my experience, the free association of haphazard ideas is a first step toward coming up with new ideas' And item #22 'My creative ideas have often started with collecting a bunch of information followed by making connections at what seems to be a subconscious level.' These item were designed to measure the 'free association.' From the Darwinian theory the presence of an element of randomness can be seen as indicative of blind-variation. Therefore when a respondent agrees with these items, this can be seen as support for Darwinian theory. The students' mean factor score is 0.125 and inventors' mean factor socre is -0.293. We can accordingly say that the students were more supportive of the Darwinian view than was the inventor group.

CHAPTER VI

CONCLUSION

6.1 Discussion

The interview data shows that there are both Darwinian and Lamarckian elements in creative thought process. Even though interviewees expressed elements of unexpected discovery from their experience in cancer research, some of them also mentioned that previous knowledge played significant role in coming up with creative solutions for cancer cure. Therefore the qualitative approach led to both unpredicted and predicted elements are involved with generating creative ideas from inventors' stories.

Considering the other items, item# 21 (I have tended to come up with new and creative ideas by connecting two or more other, very different ideas together) is the only item associated with Darwinian theory that is more supported by the inventor group than the student group. The possible explanation for this is that the creative ideas might come from when two very different ideas put together. Inventors did not support other aspects of Darwinian creative thought, however, this result might indicate that some elements of their thought processes are linked with unexpectedness like the connecting two very different ideas.

From the MANOVA result, two groups, the inventor and the student group, are different in creative thought process. From the ANOVA result, the student group has higher mean factor scores than the inventor group. Three factor scores are related with Darwinian theory and one factor score is associated with Lamarckian theory. These results led the researcher fail to reject the null hypothesis of Lamarckian theory in creative thought processes. Overall, the student group supports the Darwinian view of creative thought more than the inventor group. With the exception of the characteristic of divergent thinking, the inventors in cancer research supported the Lamarckian view more than the students.

Possible explanations for inventors support of Lamarckian theory.

Firstly, one of the possible explanations for the inventor's relatively high support for the Lamarckian hypothesis can be found in Campbell's (1960) article. According to Campbell (1960), the inventors are likely to have experienced a "Eureka" moment that actually occurred at the end of the blind variation and selection process:

> To include this process in the general plan of blind-variation-and-selective-retention, it must be emphasized that insofar as thought achieves innovation, the internal emitting of thought trials one by one is blind, lacking prescience or foresight. The process as a whole of course provides "foresight" for the overt level of behavior, once the process has blindly stumbled into a thought trial that "fits" the selection criterion, accompanied by the "something clicked," "Eureka,"

or "aha-erlebins" that usually marks the successful termination of the process (p. 384).

In other words, at the time the inventors became aware that they acknowledged a creative idea, they had already been through the BVSR process. That is, even though the inventors' responses do not tend to support a Darwinian view of the creative thought process, the moment that the inventors consciously referred to when responding to the items on the questionnaire might be the outcome of a BVSR process. Souriau (1881) also contended that inventors might forget all the agonies and trials that they have had coming up with new ideas, once he or she reached the solution for the new problem.

Secondly, Campbell (1960) contended that short-cut to full BVSR process needs to have former process of BVSR process. In other words any increase of knowledge requires BVSR process. For instance, scientists who have found the new ideas would have used their knowledge, but this knowledge would itself have gone through previous BVSR process. After having knowledge through BVSR process, this knowledge can be used without full BVSR process.

6.2 Limitations

6.2.1 Theory

The synthesis of the evolutionary theory is difficult task for testing whether creative thought behind invention is more of a Darwinian or Lamarckian process. A limitation at the theoretical level is related with the distinction between genotype and phenotype in socio-economic or psychological level. Without the clear distinction of genotype and phenotype, the result of any examination is debatable.

Studies support Lamarckian possibility in development of company using routine as the genotype (Nelson and Winter, 1982). Other examples are habit as social genotype (Hodgson Knudsen, 2006), and meme as the unit of idea evolution (Blackmore, 1999). However, these studies were failed to reject Darwinian theory because there are lack of evidence in Lamarckian process. This lack of evidence in genotype and phenotype could be less problematic for examining the socio-economic and cognitive evolution by Darwinian theory, because Darwinian mechanism can explain the development of new outcomes without interaction between genotype and phenotype (Hodgson and Knudsen, 2006).

As we saw in Chapter 3, in order to examine a Lamarckian possibility a phenotypic characteristic needs to be encoded to genotype, and it needs to be inherited to next generation. Without clear distinction between phenotype and genotype and inheritance of acquires characteristic, it is difficult to verify creative thought process either Lamarckian or Darwinian process in definitive way.

6.2.2 Survey Design

These theoretical difficulties led the researcher to obstacles of testable hypothesis and survey items. These difficulties could be partially overcome using interview data and surveys. Literatures provided directions and elements that are related with two theories. Even though the survey items are clear enough to distinguish between Darwinian or Lamarckian theory, they might have some elements that can be expressed differently.

6.3 Future Studies

Different methods, such as experiments, might be used for testing the two theories. Moreover, the distinction between genotype and phenotype could be lead to further examination of two theories. Also, different groups of creative work, such as entrepreneurs and artists, could be a sample for another study.

6.4 Implications of evolutionary theories

The theoretical debates over Darwinian theory in knowledge creation often ends up with either supporting Darwinian theory or rejecting it. Most critics of Darwinian theory in application to knowledge creation do not provide sound evidence that is capable of being falsified. Until we come up with a fundamental unit of thought process, it is difficult to provide definitive answers to whether the knowledge creation process is Darwinian or not. Of course, this does not in any way detract from its importance for economic development. This project aims to examine how we can possibly see the knowledge creation process in terms of Darwinian theory.

From the stories given by inventors in the field of cancer research, one of the main themes is that the generation process of inventive ideas involves uncertainty. Respondents indicated that their experience of finding solutions to a problem is hard to anticipate. When the problem was novel, the solution came in particularly unexpected ways. Another theme is that there is a need to have both knowledge and a notable degree of freedom of imagination for developing inventive ideas. Like an arm's movement, there is a need to have focused attention and relaxation for creative ideas. Not only is the accumulation of knowledge important, but so is the release of constraints on individuals—so as to release their imagination. The release of constrains is significant for promoting creativity.

The other theme is that inventors have tried many different ideas. The participants in the study did not know in advance what would work. This can lead to the assumption that the number of alternatives is related to having inventive ideas (Campbell, 1960). If many different ideas are pursued, there may be a greater possibility of finding a solution to the problem. Openness to variety is another point to consider. Rates of invention are likely to be increased when people are exposed to a variety of fields and ideas. Even though various fields and ideas do not seem to be linked on their face, there is a chance that they are connected from some other viewpoint. Moreover, scientists should open their mind to different possibilities in their research projects, and specifically to the possibility of error.

Lastly, previous knowledge is an important source for inventive ideas. There is evidence that the extension of previous knowledge is the major source for another invention. This theme can be viewed as evidence of supporting Lamarckian theory.

The qualitative analysis thus provides evidence that tends to support Darwinian as compared to Lamarckian theory. There are Darwinian themes that reveal the importance of having different ideas that can come from unexpected processes when there is preparation. However, there is also a clear indication in the qualitative analysis that previous knowledge strongly influences the generation of new ideas. These expressions of importance of previous knowledge might tend to support the Lamarckian framework. In a Darwinian view, both enough information from previous knowledge and unexpected creative process are required to generate new ideas. Moreover, increasing the number of alternative ideas considered as possible elements of the solution that might help escalate the probability of solving the problem.

Based on quantitative approaches, a Darwinian theory about knowledge creation particularly in cancer research was rejected in terms of statistical significance. The survey data indicate inventors' support for a Lamarckian theory of knowledge creation. The possible reason for this results can come from two explanations:1) inventors experienced blind-variation, but they forgot this process, and 2) the process of getting previous knowledge went through BVSR process (Campbell, 1960).

Implications of the Lamarckian approach. If the inventive idea is more likely to have been generated by a Lamarckian process, then may be possible to increase the rate of generating new ideas by manipulating environmental factors. Moreover, past successes and future goals can inform decisions to develop only those ideas that will be successful. From these characteristics we can possibly foretell successful ideas. Since generation of new ideas is predictable, a hierarchically organized and centralized top-down approach to economic development planning and policy is appropriate; for instance through a science-technology development strategy.

The policy implications from Lamarckian theory suggest that cause and effect relationships within environments are important factors for stimulating higher levels of knowledge creation. For example, lab facilities and research funds that are designed from top officials may induce more knowledge creation in cancer research. This also reflects the necessity of knowledge accumulation for research, especially for complex areas such as cancer research.

From environments to subjects: If inventive ideas are more likely generated from Lamarckian processes, then it is possible to increase the rate of generation of new ideas by identifying and manipulating the relevant causal factors in inventors' environments. The core of Lamarckian theory is that environments can inform the subjects to develop new traits and ideas

As a food on higher places elongates giraffe's neck, centrally planned and targeted investments in lab facilities and detailed economic plans and policies can, for instance, help scientists to develop a cure for cancer. The random elements in Darwinian processes demand much greater recognition of the underlying complications and difficulties involved in planning in the knowledge economy. The Darwinian view suggests expanding one's view of economic development problems beyond investments, to include considerations such as efficient organizational design, the degree of centralization of economic decision-making, and the roles of uncertainty, information and transactions costs in day-to-day economic development decisions. In general, centralized economic development planners and policy makers can control the knowledge formation process in Lamarckian theory.

Certainty in knowledge creation: One of the characteristics of Lamarckian theory is certainty of future status since we can possibly predict from knowledge of cause and effect relationships between variables within environments. In Lamarckian theory historical aspects and future direction are important, including *accumulation of knowledge, past successes,* and *goals*. Creativity theorists in the Lamarckian camp argue that the prior knowledge of Watson and Crick led to their discovery of DNA structure. Moreover, as giraffes develop longer necks to get foods on higher places of trees, Watson and Crick's research direction lead them to the discovery. From this argument we can say that by concentrating on the histories of cancer research—or on any other given set of problems in society—we can possibly anticipate new ideas that will be successful in the future.

Focus on a few promising fields: Lamarckian theory emphasizes specific industries and academic fields that are designed by top professionals rather than focusing on overall systems, because the theory can tell in advance about the successful ideas. As one can anticipate which idea will be successful, one can say which industry and academic field will be prosperous. For instance, the provision of healthcare can be a primary focus of a university's mission because many experts predict that the demand for healthcare will increase. Thus, universities may mainly invest in health care programs with certainty of future success.

Implications of the Darwinian approach. In general, the Darwinian view proposes diversity and localized control as the major components for the generation of new ideas and products because diversity is the critical condition for the generation of new variants. The greatest hope for the discovery of new knowledge is found within institutional arrangements designed not so much to direct outcomes in targeted areas as to the broad support of interactions between an unfathomably diverse array of individuals. In this case, each actor is in localized pursuit of his or her own individually different purposes. Moreover, the Darwinian view recommends taking a 'systemic approach' instead of focusing on 'few targets' so that the various ideas will be generated and one of them will survive the selection mechanism. The idea is to develop evolving systems for producing blind variations that can face new conditions in the future. It resembles the human immune system in that it produces various antibodies and selects one that matches the antigen (Plotkin, 1997).

According to the Darwinian view, it is appropriate to focus on the overall stock of currently existing ideas for future development, since nobody can be sure about the future status of any of the different ideas. People have limitations about deciding which ideas will be significant in the future. Francis Heyligen (1991) described it formally as "at the most fundamental level variation processes 'do not know' which of the variants they produce will turn out to be selected".

For instance, when the laser was developed, it was difficult to predict its many different uses, from medical devices to weapons. For reason of unpredictability, policy makers cannot properly judge which of the current range of ideas and fields will positively lead to success in the future. This prompts the strategy of considering overall academic and technological fields as candidates for further development instead of investing on a few specific ideas and fields.

The prescription to focus on overall fields, however, does not necessarily imply that it is a good idea to disregard particular advantages. The strength in the automobile and the biotechnology industries may not guarantee success if economic development policy makers set the goals and directions from the top and resources are limited on these sectors. Alternatively, the Darwinian framework suggests systems that academic fields and industries can provide various ideas from the bottom. Moreover, Darwinian view promotes diverse academic fields such as engineering, humanities, social science, medicine, communications, law, and education in order to broaden the opportunity for generating various ideas. The corresponding economic policies are highly decentralized, leaving the maximum possible level of discretion in the hands of local actors and researchers in pursuit of their own self-defined and self-determined purposes. If creative thought is a Darwinian process, then organizations and other cultures oriented toward blind adherence and conformity to the edicts and dictates of authority, and toward uniformity are not likely to experience equally high levels of invention in comparison to those not thus oriented.

In a Darwinian view, the probability of generating creative ideas will be increased when we can produce numerous variations. It is said that if the system can generate more new variants there will be more chance to have invention (Campbell, 1960). Therefore if there is an increase in producing the number of new variants, then there may be an increase in the chance of producing new ideas. Tolerance of individual differences and toward admitting error is put at a high premium in a Darwinian regime.

The generation process of creative ideas needs a selection mechanism that selects the good ideas. As the environment selects the ones with the best fit, social and intellectual systems need to choose the better ones that meet the standard. For instance, the level of required education can be increased so that the standard for individuals also increases. If people learn more various ideas and subjects, they will recombine those ideas to come up with different ideas. In another instance, the educational institution can also increase freedom of knowledge claims and selection standards for students to generate new ideas as well (Bowen, 2007).

The selected creative ideas need to be retained. If a good new idea is not retained, then it loses the chance of application. The unique ideas from individuals need to be tolerated. The system that can support those trials and supporting mistakes increases the chance of producing new ideas. In order to have good ideas, numerous bad ideas also need to be produced (Campbell, 1960).

Darwinian implication for economic development

Darwinian theory provides quite different policy implications than Lamarckian theory. Due to uncertainty and the serendipitous nature of knowledge creation, the recommendations of Darwinian theory focus on promotion of the overall academic fields and competing environments. In Darwinian theory the environment is not a generator of new ideas but rather serves as a selector. The process of generating new ideas is blind to the prediction of successful ideas. The main argument of Darwinian theory contends that supporting diverse cultures and opening knowledge claims are most apt to succeed at promoting the generation of different and blind ideas.

Focus on people rather than projects: In many cases, science and technology policy aims at promoting specific fields of research. The Darwinian approach would prescribe making investments in people to come up with various ideas to find a cure for cancer. For instance, we can gather smart people from various disciplines and ask them to investigate and consider new ideas even though some of those people do not have background in cancer research.

Bottom-up rather than top-down: This is similar to the previous point. Instead of having centralized planners predetermine the direction of new knowledge formation, the Darwinian view remains open to new directions. Since new ideas can come from beyond the boundaries of current knowledge, it is impossible to be certain about where and how new ideas occur. The logical implication is to provide opportunity for trial-and-error without predetermining the direction.

Ideas are bound from random process: Much as random processes lead to new species in biological evolution, so random processes lead to new ideas. Past this point, creative thought process cannot be generalized. Since each individual has different thought processes, it is difficult to predict patterns of creative thought process. The best suggestion is that creative thought can be generated from random process so policy makers and planners can provide settings conducive to creativity, not the specific directions and expected outcomes.

Tolerance for wrong ideas: The nature of knowledge creation is that there are lots of wrong ideas and only few ideas can be successful. Therefore we have to tolerate lots of wrong ideas in order to see the successful new ideas.

Culture for supporting creativity and originality: Even though support of a democratic culture is not directly related with the Darwinian approach, it emphasizes the values of self-initiative and self-responsibility in ways that go beyond those implied by a Lamarckian view. The Darwinian approach emphasizes variety, because it is the base for novelty and variety within the range of available ideas. In order to achieve this variety, a culture that recognizes and understands the value of creativity and originality is the fundamental base. Unless this is guaranteed, such as with patents and copyrights, the mechanisms for introducing new ideas will be harmed.

If Darwinian theory can explain biological evolution by variation and selection as it is accepted in many scientists of biology, there is still a logically consistent possibility that the Darwinian theory can be applied to other complex system which follows variation and selection mechanism. This possibility will remain until new data and methods definitively reject a Lamarckian hypothesis of knowledge creation.

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APPENDICES

Appendix A

Interview Protocol

These are the example questions that might be used in interview processes. Some of them are modified from *Creativity* (Csikszentmihalyi, 1996) and from committee members' suggestions. Further clarifications and developments needs to be made before actual interview process.

How did you come up with your inventive ideas?

Did you know beforehand what you were looking for?

Is there any way you could have predicted your inventive ideas?

Did you drive your inventive idea directly from your past education or experience?

Of thing you have done in life, of what are you most proud?

Has there been a particular project or event that has significantly influenced the inventive idea?

If there has been a significant person (or persons) in your life who has influenced or stimulated your inventive idea, how did they influence your inventive idea?

Where do the ideas for your work generally come from?

How important rationality versus intuition in your work?

Have you ever had a useful idea while lying in bed, or in a dream?

How do you go about developing an idea/project?

Appendix B

Survey Instruments

Title: The study of thought process in generating creative ideas

The purpose of this study is to investigate how people come up with creative ideas. The following questionnaire asks about your own thought processes as you have experienced them while generating creative ideas or inventions. This survey is a part of a doctoral dissertation, so your response will greatly affect the outcome of the dissertation. The study is being conducted by Songpyo Kim, a Ph.D. candidate at the Levin College of Urban Affairs, Cleveland State University under the supervision of Dr. William Bowen, Professor of Urban Studies and Public Administration.

Your participation in the study is voluntary. You may decline to answer any of the questions, and you may quit answering the questionnaire at any time. The information obtained during the survey will be held in a password-protected computer and will only be accessible by the researchers on the project. The results will only be reported in summary form; no individual responses will be made public. The results are completely anonymous and there are no personal identifiers attached to them. **Please return this survey within two weeks by using an included return envelop.**

If you have any questions about your rights as a research participant, you may contact the Cleveland State University Institutional Review Board at (216) 687-3630. If you have any questions regarding the study or this questionnaire, please contact Songpyo Kim, *440-503-4745, or Dr. William Bowen, Levin College of Urban Affairs, CSU (216-687-9226).*

By completing this survey, you agree to the statement above and understand your rights as a participant in this study.

Signature:____________________ Date:______________________

Instructions: This survey is about how people come up with creative ideas in the process of generating inventions, solving problems and gaining new knowledge. Take a few minutes to think about a creative moment you have experienced. Sometimes you've come up with creative ideas for your patent(s), or sometimes you may have come up with a creative new insight while solving a problem at work or at home. You might also have experienced a moment of "Eureka!" after trying to solve a puzzle or a problem that you never encountered before. These are the sorts of creative moments about which we are interested in this survey.

The following statements are drawn from discussions with inventors and theory and research regarding the experiences of people who have generated creative ideas of their own. Please respond to each based upon your own experience of creative moments. Use the following response options, 1 'Strongly Disagree', 2 'Disagree', 3 'Undecided', 4 'Agree' and 5 'Strongly Agree.' Circle the number that best describes your experience.

	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
1. I have experienced an 'A-ha' moment in which a creative idea happened unexpectedly.	1	2	3	4	5
2. My creative ideas have been informed from my previous knowledge.	1	2	3	4	5
3. In my experience, creative thought processes amount to trial-and-error for coming up with new ideas.	1	2	3	4	5
4. In my experience the generation of creative ideas is a serendipitous process, so I do not know for sure how creative ideas have occurred to me.	1	2	3	4	5
5. In coming up with creative ideas I have come up with trial ideas unintentionally, but have used my previously acquired knowledge to test and select amongst them.	1	2	3	4	5
6. Before coming up with a creative idea that actually worked in application, I first considered lots of other ideas, though most of them proved to be useless.	1	2	3	4	5
7. Sometimes a creative idea comes to my mind at a very unexpected time when I am not really trying to think about solving the problem to which the idea applies.	1	2	3	4	5

	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
8. In my experience, the essential part of generating a creative idea has come from unexpected discovery rather than advanced planning.	1	2	3	4	5
9. I can predict that my creative ideas will be generated by deliberate effort and hard work.	1	2	3	4	5
10. My creative ideas have been caused primarily from facts, events, and circumstances outside of my own mind.	1	2	3	4	5
11. The essence of a new and inventive idea is found in unexpected discovery.	1	2	3	4	5
12. In my experience, the free association of haphazard ideas is a first step toward coming up with new ideas.	1	2	3	4	5
13. My experience is that the generation of creative ideas is a serendipitous process that seems to happen almost completely by chance.	1	2	3	4	5
14. I have generated creative ideas through clear and predictable sequences of thought.	1	2	3	4	5
15. When I have been faced with coming up with new ideas in problem situations I have never encountered before, I have tended to respond to the situations based upon trial-and-error.	1	2	3	4	5
16. Creative ideas strike my mind without any advance indication or clue.	1	2	3	4	5
17. When I have come up with a creative idea I have known immediately whether or not the idea would prove to be successful.	1	2	3	4	5
18. Usually I have had a creative idea that has come to my mind when I was not trying to think of it.	1	2	3	4	5

	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
19. When I started my project I did not expect to end up with the creative ideas that I discovered.	1	2	3	4	5
20. My creative ideas have always been direct extensions of my previous knowledge.	1	2	3	4	5
21. I have tended to come up with new and creative ideas by connecting two or more other, very different ideas together.	1	2	3	4	5
22. My creative ideas have often started with collecting a bunch of information followed by making connections at what seems to be a subconscious level.	1	2	3	4	5
23. More substantial and significant discoveries involve a greater element of chance.	1	2	3	4	5
24. Sometimes I have ended up coming up with a creative idea that applied in a problem that at first I had no intention of working with.	1	2	3	4	5

25. How many patent(s) are registered under your name (please put 0 if none)? ______

26. On average, how much fund did you receive for a research that is related to a patent? $______

27. How long have you been in your research area since you completed your final degree? ______

28. In what year were you born? ______

29. Are you   Female   Male

30. What is the highest level of education you have received? (Please CHECK the one that best applies)

_____(1) Less than High School or G.E.D.   _____(5) Bachelor's degree

_____(2) High school or G.E.D   _____(6) Master's degree

_____(3) Vocational/Technical Degree   _____(7) Ph.D. or equivalent

_____(4) Associate Degree

Appendix C Group Means

Item	Group	N	Mean	Std. Deviation	Std. Error Mean
Q1	inventor	53	4.3	0.774	0.106
	student	118	4.39	0.763	0.07
Q2	inventor	53	4.64	0.522	0.072
	student	118	4.03	0.896	0.082
Q3	inventor	53	3.47	0.912	0.125
	student	117	3.5	0.925	0.086
Q4	inventor	53	2.49	1.012	0.139
	student	118	3.01	0.974	0.09
Q5	inventor	52	3.73	0.931	0.129
	student	118	3.78	0.775	0.071
Q6	inventor	53	3.26	1.041	0.143
	student	118	3.2	1.034	0.095
Q7	inventor	53	3.91	1.131	0.155
	student	118	4.21	0.904	0.083
Q8	inventor	51	3.47	1.065	0.149
	student	118	3.51	0.976	0.09
Q9	inventor	52	3.29	1.073	0.149
	student	118	2.97	1.029	0.095
Q10	inventor	53	2.79	0.968	0.133
	student	117	3	0.881	0.081
Q11	inventor	52	3.5	0.918	0.127
	student	118	3.51	0.855	0.079
Q12	inventor	53	3	1.074	0.148
	student	118	3.58	0.831	0.077
Q13	inventor	53	2.26	1.022	0.14
	student	118	2.98	0.934	0.086
Q14	inventor	53	3.66	0.898	0.123
	student	118	3.46	0.958	0.088
Q15	inventor	53	3.08	0.829	0.114
	student	118	3.23	1.008	0.093
Q16	inventor	53	3.21	1.081	0.148
	student	117	3.49	1.08	0.1
Q17	inventor	53	2.74	1.146	0.157
	student	118	2.81	1.015	0.093
Q18	inventor	53	2.85	1.133	0.156
	student	118	3.64	0.957	0.088
Q19	inventor	53	3.32	1.105	0.152
	student	118	3.41	0.954	0.088
Q20	inventor	53	3.43	1.083	0.149
	student	118	3.26	0.999	0.092
Q21	inventor	53	4.19	0.681	0.094
	student	118	3.59	0.829	0.076

Q22	inventor	53	3.77	0.933	0.128
	student	118	3.7	0.85	0.078
Q23	inventor	53	3.11	1.086	0.149
	student	118	3.05	1.003	0.092
Q24	inventor	53	3.74	0.88	0.121
	student	118	3.68	0.761	0.07

Appendix D Rotated Component Matrix

Rotated Component Matrix(a)

Component

	0.778 1	2	3	4	5		7	
v18		0.121	0.098	-0.103	0.111	0.163	0.008	0.164
v7	0.745	-0.062	-0.037	0.166	0.095	0.06	0.194	0.133
	[redacted]							
v16	0.693	0.186	-0.001	-0.062	0.063	0.128	0.081	0.075
v19	-0.135	0.	-0.109	0.083	0.236	0.225	0.143	0.216
v23	0.216	0.	-0.091	0.087	-0.097	-0.17	0.126	-0.191
v11	0.137	0.658	0.151	-0.083	-0.053	0.	-0.117	0.296
v8	0.499	0.535	-0.022	-0.026	0.012	0.218	0.037	0.016
rv2	0.09	0.092	0.803	-0.035	-0.03	0.079	0	-0.038
v21	0.051	0.189	-0.589	-0.025	-0.315	-0.259	0.193	-0.01
rv20	0.06	-0.085	0.549	0.041	0.061	-0.065	0.61	0.11
v15	0.044	0.227	-0.006	0.702	-0.1:	0.172	-0.037	0.073
v3	0.057	-0.023	-0.295	0.679	-0.05	-0	-0.071	0.133
v6	-0.017	-0.084	0.133	0.587	-0.136	-0.07	0.109	-0.189
rv17	-0.352	-0.105	0.133	0.533	0.381	-0.106	0.115	0.052
rv9	0.27	0.022	0.07	-0.117	0.	-0.066	0.115	0.094
rv14	0.328	0.19	0.179	-0.163	0.639	-0.013	-0.27	-0.153
rv10	-0.342	-0.207	-0.12	-0.295	0.497	0.26	0.072	-0.179

v4	0.221	0.048	0.111	0.011	-0.009	0.832	0.01	-0.005
v13	0.356	0.28	0.159	-0.125	0.03	0.584	-0.031	0.216
v24	0.127	0.23	-0.046	-0.085	-0.003	-0.075	0.673	0.218
v5	0.075	-0.085	-0.224	0.204	-0.183	0.377	0.495	-0.269
v1	0.381	-0.004	-0.309	0.094	0.14	0.112	0.438	-0.079
v12	0.256	0.142	0.029	0.04	0.003	0.036	0.118	0.751
v22	0.107	0.043	-0.507	0.029	-0.092	0.052	0.074	0.54

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 21 iterations.

Appendix E

IRB Approval Letter

Memorandum

To: William Bowen Principal Investigator or Advisor
Urban Studies

From: Rich Piiparinen, GA
Office of Sponsored Programs & Research

Date: April 15, 2009

Re: Results of IRB Review of your project number: 38349-BOW-HS
Co-Principal Investigator or Student: Songpyo Kim

Entitled: Inventive Minds in Cancer Cure

The IRB has reviewed and approved your application for the above named project, under the category noted below. Approval for use of human subjects in this research is for one year from today. If your study extends beyond this approval period, you must again contact this office to initiate an annual review of this research. ***This approval expires at 11:59pm on 3/28/2010.***

By accepting this decision, you agree to notify the IRB of: (1) any additions to or changes in procedures for your study that modify the subjects' risk in any way; and (2) any events that affect that safety or well-being of subjects.

Thank you for your efforts to maintain compliance with the federal regulations for the protection of human subjects.
Approval Category: Date: 3/29/2009

Exempt Status: Project is exempt from further review under CFR 46.101:

x Expedited Review: Regular

cc: Project file