POPPER'S PRINCIPLE OF FALSIFICATION AS A GROWTH MODEL AND A DEMARCATION CRITERION: A CRITICAL STUDY

MR. KRIENGSAK WONGPROMRAT

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENT FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY IN PHILOSOPHY

GRADUATE SCHOOL OF PHILOSOPHY AND RELIGION
ASSUMPTION UNIVERSITY OF THAILAND

2009

POPPER'S PRINCIPLE OF FALSIFICATION AS A GROWTH MODEL AND A DEMARCATION CRITERION: A CRITICAL STUDY

MR. KRIENGSAK WONGPROMRAT

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENT FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY IN PHILOSOPHY

GRADUATE SCHOOL OF PHILSOPHY AND RELIGION

ASSUMPTION UNIVERSITY OF THAILAND

2009

DISSERTATION TITLE: Popper's Principle of Falsification: A Critical Study

RESEARCHER NAME: Mr. Kriengsak Wongpromrat

DISSERTATION ADVISOR: Asst. Prof. Dr. Warayuth Sriwarakuel

DISSERTATION CO – ADVISOR: -

ACADEMIC YEAR: 2009

The Graduate School of Philosophy and Religion, Assumption University, has approved this dissertation as a partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Philosophy.

(Asst. Prof. Dr. Warayuth Sriwarakuel)
Dean of the Graduate School of Philosophy & Religion

Approval Committee:

.... Chairman
(Dr. Roman Meinhold)

.... Member
(Dr. John T. Giordano)

.... Member
(Asst. Prof. Dr. Warayuth Sriwarakuel)

.... Member
(Dr. Kajornpat Tangyin)

.... Member
(Dr. Siriphen Piriyachittakornkit)

Dissertation Title : Popper's Principle of Falsification as A Growth Model and A Demarcation Criterion: A Critical Study

Researcher Name : Mr. Kriengsak Wongpromrat

Dissertation Advisor : Assistant Professor Warayuth Sriwarakuel, Ph.D.

Academic Year : 2009

Abstract

The core interest of this thesis is Popper's principle of falsification, as the criterion of demarcation between science and non-science and as a model of the growth of scientific knowledge.

Many philosophers of science have criticized the principle of falsification as Popper articulated it, but that principle, especially the argument that science can grow through the practice of falsification withstands those critiques. Although alternative models of the growth of knowledge proposed by other philosophers of science differ in detail, the main concept of the growth of knowledge is the same in that advances in scientific knowledge occur when the previous knowledge is defeated by new knowledge.

The present thesis supports Popper's contention that falsification contributes to the growth of knowledge. Even where it is difficult to claim that falsification directly brings progress, at the very least it brings about change, opening up opportunities, in turn, for real progress. However, Popper narrows the application of falsification excessively when he construes it as applicable only in science. In fact, other sorts of knowledge can also be falsified and grow through the discipline of falsification. Popper is consequently mistaken in insisting on falsification as the criterion of demarcation between science and non-science. The domain for the power of falsification should be expanded for the sake of growing other kinds of knowledge.

Acknowledgements

This thesis would not have been completed if it was not for the support, both intellectual and mental, from many people surrounding me. My philosophical knowledge is credited to all faculty lecturers, who have relentlessly put their effort into grooming me in this philosophical world, making me see things in different angles. All their comments, both in and outside seminar classes, are greatly beneficial to my work.

The most important person contributing to my thesis, however, would be no other but Assistant Professor Warayuth Sriwarakuel, Ph.D., my dean and advisor. In fact, my inspiration to conduct this thesis topic has come from listening to one of his lectures. His valuable advice has guided me to complete the thesis in its proper context.

To my family, friends and colleagues, I also have to thank them for all their kind support, encouragement and understanding always.

Kriengsak Wongpromrat

Content

Chapter 1

Introduction

1.1 The Growth of Science and the Demarcation Problem

Growth is a very important issue in the philosophy of science and most well-known philosophers of science, including, for example, Kuhn, Popper, and Lakatos, are interested in the growth of knowledge, especially as it relates to the methodologies that scientists use to investigate the world and to discover its truths. It is the goal of progress in scientific knowledge to come to a more and more complete understanding of our world and of the universe. Philosophers of science have put a great deal of effort into the question of how scientific knowledge progresses, or grows. Many of them have studied the history of science in an attempt to construct a model for the growth of scientific knowledge.

The famous philosopher of science Karl Popper considered the growth of knowledge the most desirable outcome for the scientific world. From his interest in how that occurs, he developed the principle of falsification as a key element of his philosophy of science. He suggests that the scientific knowledge grows through the discipline of falsification. In other words, he thought that falsification contributes to scientific discoveries (Popper, 2000b, p. 108). The implication is that to the extent that they hope to contribute to scientific discoveries, scientists should try to falsify existing theory.

According to Popper, there are two major problems in the philosophy of science: the problem of induction and the problem of demarcation (Popper, 2000b, pp. 27-39). Popper proposed the principle of falsification as a solution to both the problem of induction and the problem of demarcation, as avoiding the problem of inductive logical inquiry and as a criterion of demarcation (Popper, 2000b, pp. 27-44).

Popper considered falsifiability an intrinsic attribute of science. All scientists who play the game of science follow this rule by trying to falsify existing theory. The rationale behind this notion was that, like other philosophers of science, he believed that searching for truth is an important task of science. Because of the problem of induction, he believed, it is impossible finally to achieve the truth, but, he suggested, we can approach the truth ever more closely through falsification. Those who claim play the game of science but do not follow the rule of attempting falsification, are not really doing science, are not genuine scientists (Popper, 2000b, p. 54).

Many philosophers of science, such as Kuhn, Lakatos, Quine, Feyerabend, and Laudan, have criticized Popper advocacy of falsification as the standard methodology in the pursuit of scientific knowledge. Their criticisms challenging the notion that falsifiability is intrinsic to science, by implication also call into question the serviceability of falsifiability as a criterion of demarcation between science and non-science.

My interest in this thesis is in the principle of falsification as articulated by Popper, considering its contribution to the growth of knowledge and its validity as a criterion of demarcation between science and non-science. My questions are whether science indeed grows through the practice of falsification. Is it the case that science is the only game that includes the rule of falsification? Is it the case that falsifiability, as articulated by Popper, can and should be used to demarcate science from non-science?

1.2 Background of the Problem of Demarcation

In order to ground my exploration of principle of falsification and its usage, an understanding of the problem of demarcation is required. This is a longstanding epistemological problem with a long history of controversy; Popper considered it the most fundamental problem.

Many philosophers of science have addressed the demarcation problem and have proposed varying solutions. Popper defines the problem as "the problem of distinguishing empirical scientific theories from other theories" (Popper, 1999a, p. 16). His objective was to define the rule that science, in particular, uses in scientific investigation.

It is undeniable that in some schools of thought, the demarcation problem is a matter of ranking science as superior to other activities. One consequence of such approaches could be warfare between science and non-science. I will not participate in such warfare, but in order to understand the development of the demarcation problem, I summarize a bit of the combat as background for the present study. Gieryn stated that the demarcation problem is a "practical problem of scientists" (1983, p. 781) who are motivated to distinguish their discipline from others.

> Construction of a boundary between science and varieties of non-science is useful for scientists' pursuit of professional goals: acquisition of intellectual authority and career opportunities; denial of these resources to "pseudoscientists"; and protection of the autonomy of scientific research from political interference. (Gieryn, 1983, p. 781)

The attempt to demarcate science from non-science has long been of philosophical interest. Among the various disciplines most frequently discussed as "non-science" in discussions of the demarcation problem are metaphysics, theology, and religion. This is because both science and metaphysics are important varieties of human knowledge, yet seem to contradict one another. In the following, I review some of the history of the conflict between science on the one hand and metaphysics and religion on the other, in order to give a brief background of the problem.

The problem of demarcation may be traced to the time when science and religion become independent of one another. From that time, and continuing today, warfare between science and metaphysics and religious belief has been an enduring element in the human community.

The origin of science may be referred to the ancient Greeks in the fourth century before Christ, when a museum was established in order to carry out scientific activities for the purpose of gaining knowledge. John William Draper (1881) started his treatise *History of the Conflict between Religion and Science* with a background of the origins of science:

> Religious condition of the Greeks in the fourth century before Christ -- Their invasion of the Persian Empire brings them in contact with new aspects of Nature, and familiarizes them with new religious systems. -- The military, engineering, and scientific activity…, lead to the establishment in Alexandria of an institute, the Museum, for cultivation of knowledge by experiment, observation, and mathematical discussion. (Draper, 1881, p. 1)

The history of science and metaphysics and religion suggests that their relationship tend to be conflictual. Throughout the history of science, contention between science and religious belief has repeatedly come into play. The emergence of science affects belief in religion. Draper elaborated various conflicts between science and religion, including, for example:

- The conflict respecting the nature of the world. While the "Scriptural view of the world: the earth a flat surface; location of heaven and hell.... Scientific view: the earth a globe; its size determined; its position is and relations to the solar systems" (Draper, 1881, p. 152) which was proved by the journey of Columbus.
- The conflict respecting the government of the universe. While religious belief is that the universe is governed by Providence, science believes that universal laws govern the universe as a system. That scientific belief led to Kepler's discovery of the laws of planetary motion, Newton's application of mechanical knowledge and the laws of dynamics to explain the movements of celestial bodies (Draper, 1881, p. 228), and, in our time the theory of the Big Bang.

The history of the battle between science on the one hand and metaphysics and religious belief on the other indicates that science has grown more successful as it gains acceptance from the human community. Andrew Dickson White, former president and professor of history at Cornell University, elaborated on the combat between science and religion throughout history in his treatise, *A History of the Warfare of Science with Theology in Christendom* (1898). He recounted many cases of the battle between science and religion, and it seems, in his book, that science has won the battle. The Darwinian theory of natural evolution has challenged theological teachings on the origin of man and other living things which refer to divine creation. The picture of the geography of the earth has radically changed from that of a flat earth to that of a sphere. Astronomically, the heliocentric theory has overturned the geocentric, presented by White as an illustration of combat between the Church and scientists, specifically Galileo. The emergence of chemistry and physics has triumphed over primitive beliefs in the supremacy of magic. (White, 1898, "The Final Effort of Theology" and "The Triumph of Chemistry and Physics")

In line with the conflict between science on the one hand and metaphysics and religion on the other, there have long been attempts to distinguish science from metaphysics. Philosophers of science, such as the positivists and Popperians, attempted to demarcate science from other disciplines by identifying a standard methodology used only in science in pursuit of scientific knowledge and that contributed to the growth of science, the most desired goal of scientists.

One significant proposal of a principle demarcating science from non-science was the principle of verification, proposed by the logical positivists. The principle led to many controversies, as it not only embodied the desire to demarcate science from non-science, but also to eliminate non-scientific knowledge from human interest. The logical positivists sparked warfare between science and metaphysics in the epistemological realm.

1.3 The Principle of Verification as Criterion of Demarcation

The logical positivists have extreme respect for scientific knowledge and reject all other kinds of knowledge, such as metaphysics, as meaningless.

Writing of the relationship between Popper and Vienna Circle, the most prominent group of logical positivists, Kraft states “Popper’s work cannot be genetically understood without reference to the Vienna Circle. As Popper stands in a close, inextricable relationship with the development of Vienna Circle, so the Circle was also of essential significance for his own development” (Kraft, 1974, p. 185). Therefore, to understand Popper’s philosophy of science we have to have some basic concept of the logical positivism of the Vienna Circle, especially the principle of verification.

According to positivism, the only authentic knowledge is scientific knowledge. This means that knowledge can only be acquired through the rigorously positive affirmation of theories through scientific method. For them, scientific propositions alone are meaningful; all other kinds of proposition are meaningless. Most logical positivists believe that all knowledge is based on logical inference grounded in observable facts, or empirical truths. They esteem only scientific knowledge and support forms of materialism, philosophical naturalism, and empiricism, and reject theology, ethics, and metaphysics as based on the existence of non-empirical beings (Hamlyn, 1990, p. 307).

The most prominent concept of logical positivism is the *principle of verification*, that is the verifiability criterion of meaning, or verificationism, influenced by the early Wittgenstein’s *Tractatus Logico-Philosophicus*. (Hamlyn, 1990, p. 307)

Wittgenstein writes in the *Tractatus* that all valid propositions must be capable of proof. A problem with no means of resolution is not a problem at all: it does not exist. Proposition 6.5: “When the answer cannot be put into words, neither can the question be put into words. The riddle does not exist. If a question can be framed at all, it is also possible to answer it," (Wittgenstein, 1992).

He seems to say, in propositions 6.53, 6.54 and 7, that metaphysical propositions are meaningless, and ultimately to be rejected, not as false, but as lacking in sense.

> 6.53 The correct method in philosophy would really be the following: to say nothing except what can be said, i.e. propositions of natural science--i.e. something that has nothing to do with philosophy -- and then, whenever someone else wanted to say something metaphysical, to demonstrate to him that he had failed to give a meaning to certain signs in his propositions.
>
> 6.54 My propositions are elucidatory in this way: he who understands me finally recognizes them as senseless, when he has climbed out through them, on them, over them. (He must so to speak throw away the ladder, after he has climbed up on it).
>
> 7 What we cannot speak about we must pass over in silence. (Wittgenstein, 1992)

The positivists then use verifiability, as they define it, as the criterion demarcating science from non-science. The positivist criterion of demarcation is also called the criterion on meaning. Any proposition that can be verified as true or false is a scientific proposition, and therefore, a meaningful proposition. Any proposition for which no means of verification, whether it is true or false, is a proposition of non-science, a meaningless proposition.

Logical positivist A.J. Ayer gives his version of the principle of verification as, “We say that a sentence is factually significant … if, and only if, [one] knows how to verify the proposition [meaning] which it purports to express,” (cited in Hunnex, 1986, p. 14).

A proposition is meaningful for the positivists only in the case that there is at least one finite procedure to verify, or conclusively determine, whether it is true or false; such a procedure could only be empirical. Non-verifiable propositions, that is, propositions for which there is no method of determining their truth or falsity are meaningless. By this principle, metaphysical, theological, and ethical propositions are meaningless since they cannot be empirically verified. A corollary that may be inferred from the principle of verification is that the opposition between rationalism and empiricism is an opposition between metaphysicians and verificationists, or antimetaphysicians (Hunnex, 1986, p. 7). The empiricist holds that significant truth is be verifiable, while the rationalist holds knowledge from both verifiable and non-verifiable sources.

The basic methodological concept advocated by logical positivism is inductive, and induction is typical of the methods by which scientists inquire into the truth of the world. Verification is a methodology that science could apply to expand scientific knowledge through inductive logic. With the inductive method, scientists move from particular results of experiments or observations to universal theories. The principle of verification articulates the positivist belief that scientific knowledge grows through verification. Therefore, to search for expanded knowledge is to verify truth, and the positivist would verify truth inductively.

The principle of verification as the criterion of demarcation between science and non-science poses a strong confrontation of science with non-science, especially metaphysics. The only valid knowledge originates in the empirical sciences, and, therefore, there is no room for metaphysics or religious belief.

I agree with Popper that the principle of verification is too stringent in that it seeks not only to demarcate science from non-science but also to eradicate metaphysics (Popper, 2000b, P.36). Any notion that respects only science and treats other kinds of knowledge as meaningless is too limited, as other approaches, such as metaphysics and religion, have also played a critical role in human existence, and continue to do so in the present.

But beyond those considerations, Popper argues the principle of verification is not, in fact, a workable criterion of demarcation.

1.4 Popper's Critique of the Principle of Verification as the Demarcation Criterion

It is well known that Popper challenges the inductive method with the problem of induction (Popper, 2000b, p. 27). He states that "my main objection reason for rejecting inductive logic is precisely that it does not provide a suitable distinguishing mark of the empirical, non-metaphysical, character of a theoretical systems; or in other words, that it does not provide a suitable criterion of demarcation." (Popper, 2000b, p. 34).

The two most important and fundamental problems in Popper's philosophy of science are the problem of induction and the problem of demarcation, and he stated clearly that the problem of demarcation is "more fundamental". He thought that the basic reason scientists adhere to the inductive method as the main route to acquiring knowledge is "their belief that this method alone can provide a suitable criterion of demarcation" (Popper, 2000b, p. 34). From this statement, it is evident that he disagrees with logical positivism choice of a demarcation criterion. A corollary is that the principle of verification is not appropriately used as the criterion of demarcation.

The demarcation problem does not belong to the sphere of science but to the philosophy of science. That is to say it is not an "empirical scientific problem", but rather a "theoretical scientific problem", in the realm of "logic or philosophy of science," (Popper, 1999a, p. 16).

A consequence of Popper's rejection of inductive logic is that the principle of verification as the criterion demarcation must also be rejected.

He strongly rejects the verificationist's assumptions of the possibility to verify universal truths. Empirical science only yields singular events, but "verification of a natural law could only be carried out by empirically ascertaining every single event to which the law might apply, and by finding that every such event actually conforms to law – clearly an impossible task" (Popper, 2000b, p. 63). Simply said, according to Popper, it is impossible to ascertain universal truths.

The aforementioned states that the problem of demarcation is the most fundamental problem for the philosophy of science. Popper adds that if we could solve the problem of demarcation, we could also find a solution to the problem of induction (Popper, 2000a, p. 54). Hence, rejecting the principle of verification as the criterion of demarcation requires us to undertake the task of searching for a better, acceptable criterion. This is because to reject the principle of verification is to reject the belief that that science uses a methodology of verification to grow knowledge. The question here is, if we refute the verification approach, what, conceptually, then, is the methodology that scientists could use instead to grow scientific knowledge. Popper suggests that science progresses through falsification rather than through verification. He believes that falsifiability is an intrinsic characteristic of science and scientists should endeavor to falsify existing theory because success in falsifying a theory contributes to the growth of knowledge. Hence, rather than verifiabity, he suggests using falsifiability as the criterion of demarcation. Falsification then functions as the rule for scientific investigation for the growth of knowledge (Popper, 2000b, p. 35).

Another view that I admire in Popper is that, even though he is widely accepted as a major philosopher of science, he does not look down on other branches of knowledge. Popper rather criticized logical positivism for their use of the words "meaningful" for empirical scientific propositions and "meaningless" for non-empirical propositions as a "derogatory evaluation" resulting in their failure to overthrow and annihilate metaphysics (Popper, 2000b, p. 36).

Popper expresses his opposition to taking the principle of verification as the criterion of demarcation, by stating, in one place, that "the repeated attempts made by Rudolf Carnap to show that the demarcation between science and metaphysics coincides with that between sense and nonsense have failed". He believes that this positivist's approach to demarcation was "inappropriate" because "metaphysics need not to be meaningless even though it is not science" (Popper, 2000a, p. 253).

Popper's most telling point, in my opinion, is that the inductive criterion of demarcation fails to demarcate science from the metaphysics, finally, because both science and metaphysics ultimately fall into the meaningless category. According to the principle of verification, to be meaningful, a proposition must be verifiable or justifiable. But the problem of induction, as Hume argues, suggests to us that it is, after all, impossible to justify any universal proposition about reality (Popper, 2000b, p. 37). Therefore, no proposition can be verified as universally true, and no scientific proposition is a genuine proposition.

1.5 Popper's Solution to the Problem of Demarcation

The problem of induction leads us to conclude that theories are "never empirically verifiable" (Popper, 2000b, p. 40). Therefore, verifiability cannot be counted as a tool of scientific discovery and the principle of verification is not a valid criterion of demarcation between scientific and non-scientific propositions.

The rejection of inductive logic as a criterion raises the question, what is a more appropriate criterion to demarcate science from non-science. Popper, again, also would like to identify the distinction between science and metaphysics, as he ranks the problem of demarcation as the most fundamental problem for the philosophy of science. He corrects the mistake of demarcation by inductive logic by proposing a new tool for scientific growth which at the same time functions as the criterion that "allows us to admit to the domain of empirical science even statements which cannot be verified" (Popper, 2000b, p. 40). In particular, he proposes the principle of falsification.

While most people prefer and seek the truth, no one wishes to pursue falsity, but Popper exploits falsification brilliantly. He proposes falsifiability as the criterion of demarcation between science and non-science because it is an attribute of scientific propositions. Although scientific propositions cannot be verified, as indicated by the problem of induction, it is clear that it can be tested by experience in which test results might possibly falsify them. Therefore, Popper proposes falsifiability in place of verifiability as the criterion of demarcation (Popper, 2000b, p. 40). Any statement or theory that we can find a means to falsify is scientific. On the other hand, any statement or theory that we cannot find any means of falsifying is non-science.

The principle of falsification is proposed in response to the failure of the principle of verification to distinguish science from non-science. While the problem of induction prevents us from verifying empirical propositions, it does not prevent us from falsifying them. Hence, falsifiability as the demarcation criterion is an advancement over verifiability since it overcomes the problem of induction.

In *Conjectures and Refutations*, Popper addresses Carnap's attempts at compromise by substituting testability and confirmability for verifiability. Popper rejects these proposals as no more than attempts, "to escape the objection that laws are not verifiable" and judges that, "this compromise is inadequate" (Popper, 2000a, p. 279).

1.6 Critics of the Principle of Falsification

A number of philosophers of science such as, for example, Kuhn, Lakatos, and Quine question the contribution that falsification makes to the progress of knowledge. For example, Kuhn strongly opposes the falsification hypothesis, doubting the actual practice of falsification in scientific inquiry (Kuhn, 1970, p. 146). To clarify the controversy between Popper and those philosophers who criticized the principle of falsification, I would like to inquire into the question whether scientific knowledge can in fact be grown through the falsification approach.

Another important problem is falsifiability constitutes a suitable criterion demarcating science from non-science. Even if it is granted that the principle of falsification resolves the problem of induction that plagues the principle of verification, there are critics who point to weakness in the principle of falsification as the criterion of demarcation between science and non-science, especially metaphysics.

There are a number of examples for which Popper's criterion appears to fail to distinguish science from non-science. One obvious example is Darwinian biological evolution which is certainly science but can be falsified. Psychoanalytic theory is another problem for the falsification criterion (Grunbaum, 1989, p. 392); by that criterion, psychoanalysis is not science and it would seem that Popper's approach does not apply to this sort of knowledge. This is because psychoanalysis is always already able to explain any observed behaviour: "psychoanalysis can always explain the most peculiar human behavior. It is therefore not empirically falsifiable; it is not testable." (Popper, 1999a, p. 17). There are certain types of proposition that resist falsification and whose existence thus calls into question the use of the principle of falsification as the criterion of demarcation, specifically, the existential statement and probability statements (Gillies, 1993, p. 205).

I would like to add my own doubt about applying the principle of falsification to delimit science and non-science. For example, by the falsification criterion, "there is a spirit" would be a metaphysical, not a scientific proposition. However, there are many cases in which people, including scientists, try to determine the truth or falsity of such statements, and it is possible that in the future a means may be found to test them. Therefore, some what are now considered metaphysical propositions by Popper's criterion may possibly become scientific propositions in the future when means are discovered to falsify them. This may lead us to the notion that, finally, there is no distinction between science and metaphysics, to the extent that we adopt the principle of falsification as delimiting them. Throughout the history of science, many non-falsifiable, metaphysical, statements later came to be falsifiable. For instance, lightning was believed to be the act of a goddess. But science has now falsified that belief, which presently retains the status of as a folk tale. Lightning is, then, explained in scientific manner.

These are examples of critiques of the falsifiability criterion of demarcation. Although Popper put a great deal of effort into solving the problem of demarcation, his proposal has not been the final word. Inasmuch as Popper understood the problem of demarcation as closely connected to the growth model of scientific knowledge (Popper, 2000b, p. 40), weakness in his solution to the problem of demarcation infects the growth model of knowledge that he formulated.

No matter how far we may have come in the search for a suitable model of the growth of scientific knowledge and a suitable criterion of demarcation, the quest is not complete. I would like to participate in the search hoping to contribute something towards finding solutions.

1.7 Thesis statement

1. Falsification leads to change in scientific knowledge and contributes to the growth of knowledge.

The first statement is intended to show my support for Popper's notion that falsification can contribute the scientific discovery. I say "change" instead of "progress" in scientific knowledge as I expect that change is more responsive to falsification. Nevertheless, without room for change, there is no room for growth.

2. The principle of falsification has weaknesses as the single criterion of demarcation between science and non-science: falsification can apply to both science and non-science.

I agree with Popper that the problem of induction prevents verification of universal truths, and that the principle of falsification successfully resolves the problem of induction that obtains when the principle of verification is used as the only criterion of demarcation. However, the principle of falsification has some weaknesses as the criterion of demarcation between science and non-science. Falsification may also be applied in other realms knowledge and contribute to growth in those other realms.

1.8 Objectives

- To study Popper's philosophy of science, especially the principle of falsification.
- To critically examine Popper's proposal that falsification be used as a method leading to the progress of knowledge.
- To critically examine weakness in applying Popper's principle of falsification as the criterion of demarcation between science and non-science.

1.9 Scope and Limitations

- A great many criteria have been proposed to demarcate science from non-science, leading to many kinds of discipline. Not all such proposals will be reviewed, rather this thesis will focus on notions that are relevant to falsifiability as the criterion of demarcation, as proposed by Popper.
- Popper was one of the great philosophers of the 20th century. He proposed many critical philosophical concepts, especially in the philosophies of science and of politics. This thesis will focus on his articulation of the principle of falsification. Other aspects of his philosophy will be inquired into only as required by the context.

1.10 Research Methodology

Extensive documentary search is the key source of input, the most important sources being the primary treatises of philosophers, especially of Karl Popper. Secondary treatises, books, theses, articles, journals, and the like will also be perused to survey various interpretations, opinions, critical assessments and other notions as relevant to the topic.

Qualitative analysis is applied to analyze and critically examine the gathered notions and opinions for the purpose of meeting the objectives.

Certainly, dialogue, discussion, and consultation with philosophers, professors, gurus and others who are interested in similar topics, are conducted in the course of the research in order to reflect upon and to refine my positions.

Chapter 2

Science and Philosophy of Science

2.1 Development of Scientific Knowledge

Science has produced the most influential knowledge of recent times. The emergence of scientific knowledge has impacted all on facets of human existence. The physical, psychological and mental aspects of being human, including our ways of living, notions, and beliefs have come to adhere to science. It is in terms of scientific knowledge that we understand our bodies and how the organs in our bodies function. Physicians utilize scientific knowledge to alleviate sickness. In our daily lives, we are addicted to products made possible by scientific development. In the morning, many people are awaked by an alarm clock instead of a cock. When cleaning our mouths, we use a toothbrush and toothpaste rather than tree leaves as our ancestors used to do. We clean our bodies with soap and wash our hair with shampoo rather than with water alone. We wear clothes woven of synthetic fibers. Most of us go quickly to work by vehicle, though some may walk. In the work place, we operate a variety of equipment in the course of the day. When we return home, television, radio, and video players are our inseparable companions. Sleep would seem to be the only time that we are detached from the things of science and technology. But in fact, we sleep on spring mattresses, under an electric fan, air conditioner, or heater until we are awakened again by the alarm clock. Alarm clocks, synthetic fiber, toothbrushes, toothpaste, vehicles, office equipment, production machines, entertainment devices, comfort devices are just a few of the things consequent on scientific knowledge to which we are attached. All the basic needs of human life, food, lodging, clothing, and medicine, together with our wants and desires are entangled with science. Hence, it seems that in our daily lives there are only very rare moments, if there are any at all, that we are without science. Thus science far outstrips other sorts of knowledge today, and I would maintain that scientific progress has contributed a great many vital things to human existence. However, there are also many cases in which human beings have wrongly exploited scientific knowledge for only short-term satisfaction, creating many of the problems of our time. The most critical and well-known such problem is global warming, which impacts the whole world. While the applied sciences benefit humanity in many ways, they also produce many problems for the world, either by intention or through ignorance of side-effects. I would blame human beings for the negative impacts of science. Actually, pure science aims at unveiling the truths of the world, at understanding nature, but we do not stop with that knowledge, and instead of adapting ourselves to live peacefully with nature, too many of us attempt to control nature, to bend nature to the way we want it to be. Hence, scientific knowledge itself is not harmful; what is harmful is rather the humans who misuse that knowledge.

If one asks what is at the center of scientific interest, the answer is the "world". Science is the study of the world, especially the empirical world. Fetzer wrote that, "the goal of empirical science is to construct a model of the world" (1993, p. xii). Science aims to explain all our experiences and the phenomena that surround us, both direct experience through the senses and indirect, inferred experience. Scientific theories are typically grounded in evidence and reason. Through scientific method, science discovers principles that answer questions to which the ancients, unable to find concrete answers, responded mythologically. For example, they believed that lightning and thunder were produced by gods. Disasters such as draught or flood, destroying crops and human lives, were attributed to gods or mythological powers, perhaps as retribution for wrongdoing. These phenomena can now be rationally explained through scientific knowledge and through the progress of science; mythological beliefs are shown to be mistaken.

2.2 What is Science?

Science stands for the knowledge of our physical world, our universe. It is the duty of scientists to inquire into the structures of the world seeking logical and acceptable explanations of phenomena. Scientific progress provides answers to numerous questions about the world, including, for example, knowledge of the cosmos, the relationship between the sun, the earth, and other objects in the universe, the physical force that holds us to the earth even though it is a sphere, and the functions of the bodily organs.

As scientific knowledge has been so successful in today's world, science seems to have become the standard of knowledge, superior to all other sorts of knowledge. In the broadest sense, science seems to include all significant sorts of knowledge. There are many ways of categorizing science, but after extensive review I would divide it into four major categories.

- The *Natural Sciences* aim to understand the phenomena in the natural world, to discover the why and how of each phenomenon. The formulation of a theory that explains all natural phenomena is an ultimate objective. The fruit of natural science is "the intellectual understanding it gives us of the world we live in," (Salmon, et. al, 1992, p. 7). The natural sciences include:
    - Physical science
        - Chemistry

    - Physics
- Space science
- Earth science
- Environmental science
- Life and behavioral sciences
    - Biology
    - Psychology (Klemke, Hollinger, Kline, 1980, p. 11)

- *Formal science* involves the logical form of knowledge. Formal science plays a very important role in other sorts of knowledge, such as mathematics and logic, which, in turn are fundamental to other realms of knowledge. In the process of synthesizing hypotheses, theories, and laws, or when searching for an explanation of any phenomenon, mathematics and logic have an essential function. Formal science includes:
    - Mathematics
    - Logic (Klemke, et al., 1980, p. 11)

- *Applied science* refers to the application of knowledge from the natural, life and behavioral, and formal sciences to practical concerns in actual life. In other words, applied science utilizes knowledge for specific purposes. For example, chemical engineering applies the knowledge of physics, chemistry, mathematics, and logic and medical science makes practical use of biological knowledge. The applied sciences include:
    - Architecture
    - Engineering
    - Computer science

- Health science
  - Medicine
- Military science
- Agriculture (Klemke, et al., 1980, p. 11)

- *Social science* is the pursuit of knowledge of human society. Social science tries to understand human society "using the same methods that have been so successful in the physical sciences," (Salmon, et al., 1992, p. 5). The social sciences covers various aspects of human community under a variety of disciplines:
  - Anthropology
  - Economics
  - Geography
  - Linguistics
  - Philosophy
  - Political science
  - Sociology
  - History
  - Education
  - Law/Government
  - Management (Klemke, et al., 1980, p. 12)

Though it would appear that science covers most realms of knowledge, it is typical to think of science in terms of the natural sciences, though some may include also the life and behavioral sciences and formal science. When scientific knowledge is mentioned, the natural and biological sciences are among the disciplines that first come to mind. The social sciences are often not at the forefront of what we commonly think of as science. Philosophers of science have sought to formulate a rule distinguishing science from non-science and the different philosophies have proposed different ways of drawing a line of demarcation. Karl Popper, for example proposed falsifiability as the line of demarcation (Popper, 2000b, p. 40) between science and non-science.

2.3 Typical Scientific Method

The typical method that a scientist uses to gain knowledge begins with an observation of phenomena and formulating a question concerning the empirical world. When scientists observe a fact of the world, they are curious about the observation, and wish to satisfy their curiosity with new knowledge of the observation and a better understanding of the world. In order to satisfy their curiosity, scientists formulate it as a question that they hope to answer, allowing them to focus on a specific issue, defining the scope and target of inquiry.

A hypothesis is formulated as a guideline for answering the question. Scientists normally construct a hypothesis from what they expect might be the answer to the question. The target of inquiry is the truth or falsity of the hypothesis. An unsuitable hypothesis could lead to fruitless inquiry. Scientists hope to determine whether the hypothesis should be accepted or rejected. However, a poorly formed hypothesis will lead to inapplicable experimental results. The foundations of good hypothesis formation are rationality, prior knowledge and experience, and related theories. A good hypothesis does not arise from a haphazard notion. Given the specific question, before testing the truth of a possible answer, scientists utilize reason, past experience, prior knowledge, and related theories to facilitate the determination of truth.

To test a hypothesis, scientists design a system for testing. This is the step at which scientists identify means of checking the truth of the hypothesis. The testing system is designed in response to the specific point of interest leading to an answer to the question. This is an important step in scientific inquiry. A good system will lead to answers whereas a poor system will result in time wasted. Even if the hypothesis is appropriate to the question, it is impossible to have a good result if the test system is poorly designed. A poor system may not merely fail to yield results, but even worse, may lead to wrong conclusions taking us farther from the reality. How can we achieve the goal of answering the question, of inquiring into phenomena in pursuit of knowledge, if the way leading to knowledge is wrong? A good test system design is required in order to pave the way to reliable experiments and results.

The experiment, or experience of fact, is the observational step following the design of a system for testing the hypothesis. The test results may either confirm or deny the hypothesis. If the results show that the hypothesis does not answer the question, the scientist would need to redefine the system of inquiry, seeking other means of acquiring a true understanding of the subject of interest. If the results confirm the hypothesis, normally scientists will repeat the experiment to ensure that it gives the same results. The more often the result is replicated, the more confident scientists become of the reliability of the experiment. Repeated replication of results, that is reliability, give scientists confidence that their hypothesis is useful and able to determine the truth of the matter. At this point they will develop the hypothesis into a theory that answers the question about the world. The theory will be then be taken as knowledge that can be used as a foundation for further explanations and research.

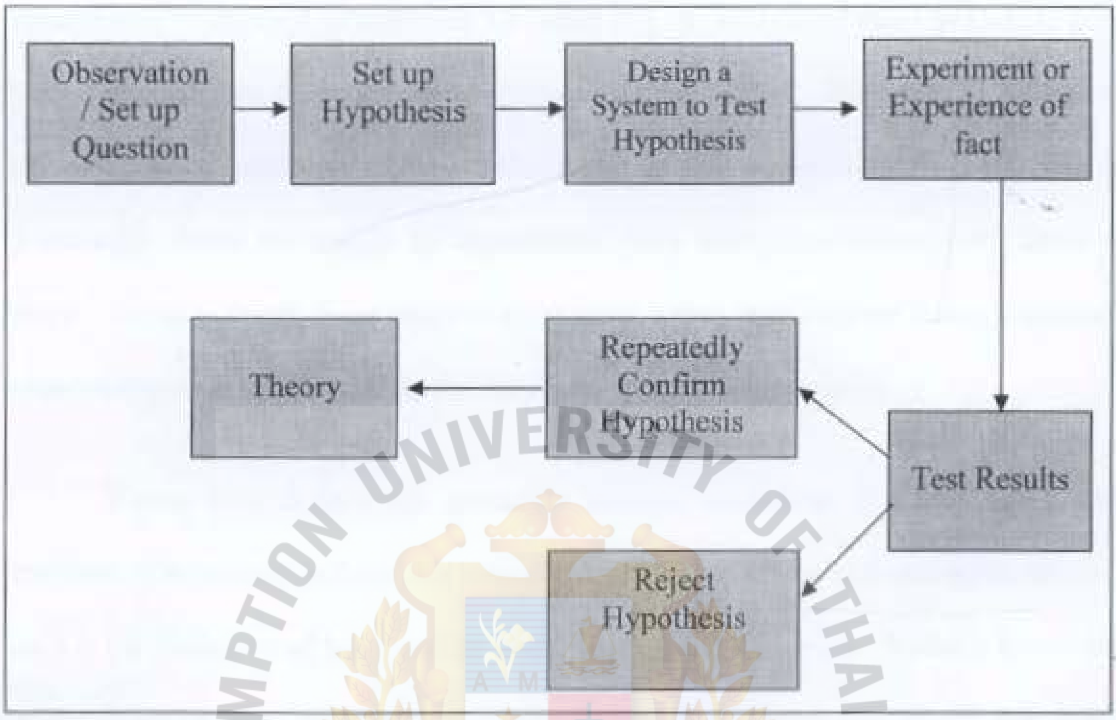


Figure 2.1: Typical Scientific Method

It is obvious from the scientific method as sketched above, that it depends on a system of empirical testing to discover truth. Only experience in the empirical world, typically through experimentation, can justify accepting or rejecting a hypothesis. Experimental results may either directly bear on the problem or may do so only indirectly, in which case scientists must infer their bearing on the truth or falsity of the hypotheses. However, all scientific data, whether direct or indirect, are acquired through empirical experiments or observation: they are empirical facts.

Therefore, given the scientific method as sketched above, scientific knowledge is limited by what we can experience. That which cannot be experienced, if it exists, is beyond the scope of science.

2.4 Science and Induction

It is obvious that scientists utilize inductive logic in the process of discovery. Induction is "a method of reasoning in which you use individual ideas or facts to give you a general rule or conclusion," (Sinclair, 2006, p. 740). Induction is central to scientific investigation because scientists use inductive methods in the acquisition of knowledge. From the results of experiments, they make conclusions formulated as theory. In other words, from singular statements, which they confirm through repeated observation or experimental results, they infer universal knowledge.

Those who defend the inductive method, including, I would argue, the majority of scientists, believe that inductive inference is essential to scientific inquiry, as it is the fundamental logic for the scientific discovery of truths. Without induction, science would lose its means of finding empirical truths and could not make distinctions between what is true and what is false. Therefore, science would not be a source of concrete knowledge but rather would belong to the realm of folktale or fiction. Popper writes that, "without it [inductive method], clearly, science would no longer have the right to distinguish its theories from the fanciful and arbitrary creations of the poet's mind," (Popper, 2000b, p. 28). We may conclude here that the method of empirical science is inductive.

It is typically believed that scientific inquiry is based on induction, that the method of empirical science is inductive. Therefore, the analysis of scientific method involves the analysis of induction. Hence, the philosophy of science is inevitably concerned to analyze inductive methodologies.

However, if we analyze typical scientific method as sketched below, it would appear that scientists utilize both deductive and inductive methods in their research. In the early stages of inquiry, scientists utilize deductive logic. After making an observation and formulating questions, the scientist formulates a hypothesis and designs a system to test the hypothesis, by deduction from existing knowledge and theory. The anticipated results or answers yielded by the test are also deduced from the current system of theories.

Inductive logic comes into play after testing has been completed. If the results repeatedly confirm the hypothesis, scientists use induction to move from those results to new theory or law, or the confirmation of existing theory. Even if the results deny the truth of the hypothesis, thus falsifying the theory, it is also an inductive operation to generalize from a single negation to the falsity of a universal statement.

It must be added that theories and laws, once discovered, are of benefit not only in understanding natural phenomena, but also, and more particularly, in predicting future occurrences through deduction. Popper thought formulating theories and laws for the sake of deductive prediction is a very important task of natural scientists (Popper, 2000b, p. 246).

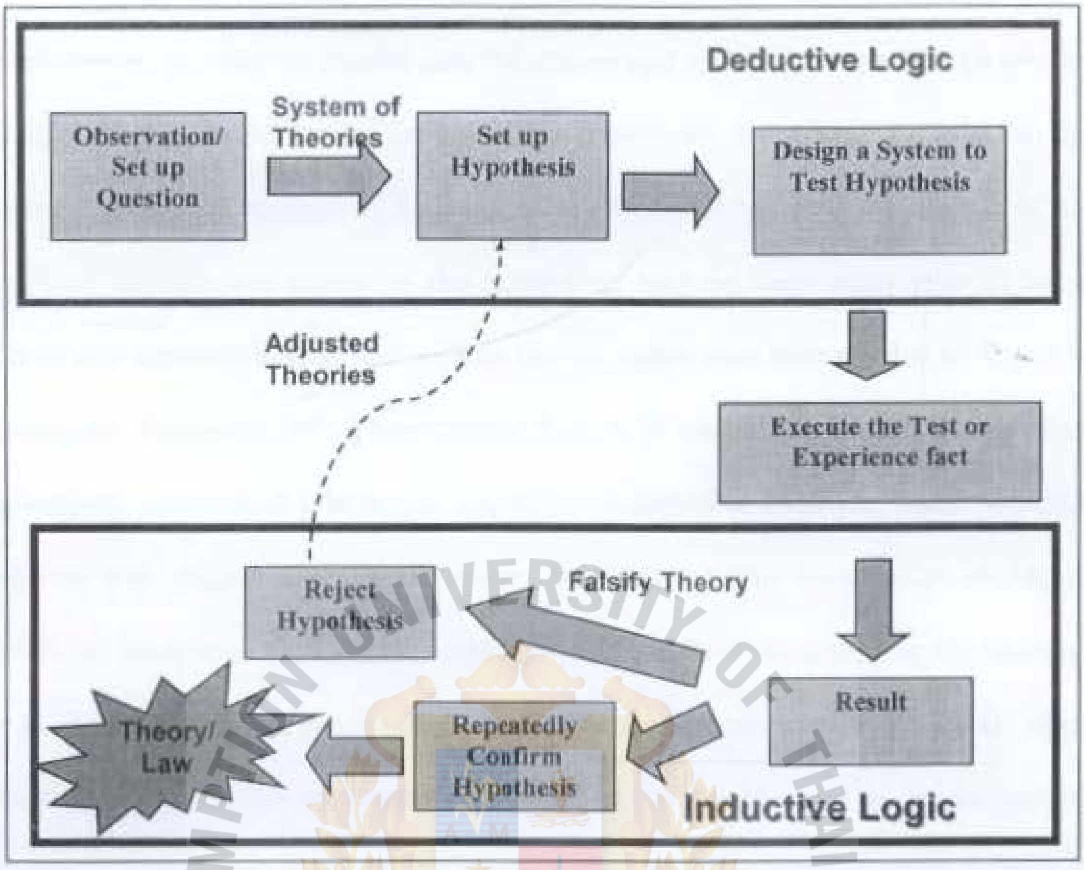


Figure 2.2: Logical Forms in Scientific Methodology

2.5 Scientific Methodology for Seeking Truths

In seeking truths, the scientist is interested in only a very specific issue. When a scientist has completed a piece of research, he directly inquires into the heart of the problem that interests him. In an experiment, a typical scientific procedure for searching for truth, there are variable and controlled factors. Variable factors make up the focal point of interest, with the scientist hoping to learn the effect on the experiment of changing the conditions of the variable factors. Controlled factors constitute the context of an experiment in which scientists fix certain conditions throughout the experiment with the intention of eliminating the influence of external factors over the results.

In ordinary life, there are a great many factors affecting any given event or phenomenon. In order to inquire into the causes and effects of a specific factor, the scientist must control all other factors. If the experiment is not well controlled in the sense of fixing all extraneous factors, the scientist will not find the answer to his questions because the results of the experiment may be the consequence of other factors or a combination of other various factors, rather than the ones that he hoped to investigate. Therefore, fixing surrounding factors, or controlling the conditions of an experiment, is standard practice in scientific research. For example, water normally boils at 100 degrees Celsius. However, it boils at lower temperature at higher elevations because of the lower atmospheric pressure. So if the experiment is intended to discover or confirm the boiling point of water, the scientist must fix all other conditions, such as the atmospheric pressure on the sample, and by increasing the temperature only gradually until the water boils. Then, the scientist could go further with a series of similar experiments at different pressures; each experiment would maintain a single set of conditions, that is, maintain the same atmospheric pressure while increasing the temperature to boiling point. After completing the series of experiments, the scientist would have information on the boiling point of water at different atmospheric pressures. If the scientist would like to know the effect of other factors on the boiling point of water, for example impurities such as salt or sugar, he would employ the same methodology but changing and controlling the condition, for example the concentration of salt in the solution, whose effect on the boiling point he hopes to learn. This is the process that scientists generally use in searching for truths about the world, the analysis and synthesis of knowledge. They analyze by separating the phenomena into parts and studying each specific part in depth. After gaining knowledge of various influent factors, they combine that knowledge, synthesizing it into a broader understanding.

2.6 Scientific Problems and Philosophical Problems

In the preface to the first edition of *The Logic of Scientific Discovery*, Popper writes that there seems to be consensus that scientific problems are genuine problems, whereas the genuineness of philosophical problems is in dispute. Scientific problems are obviously genuine as their structure conforms to a "generally accepted problem-situation". The presently accepted structure of scientific knowledge consists of the body of knowledge that all scientists accept and which forms the basis of the formulation of problems and inquiries. When a scientist makes a new discovery or falsifies previously accepted theory, then, to the extent that other scientists come to accept his results, the generally accepted structure of knowledge will be modified to accommodate the discovery. That revised structure of scientific knowledge will, in turn, be readily open to new challenges. In short, there is a generally accepted, and empirical, body of knowledge in science. All scientific problems are based on this empirical knowledge and it is therefore obvious to everyone that scientific problems are genuine problems. When a scientist inquires into an issue, he is able to inquire straightaway into the heart of the problem through the accepted scientific structure (Popper, 2000b, p. 13).

Popper elaborates on the philosophical dispute over whether or not philosophical problems are genuine. It may be argued that analytic philosophers, such as Carnap, think that philosophical problems are not genuine. They do not conform to a generally accepted problem situation such as we find in scientific problems. They argue that there are no genuine philosophical problems, because such "problems" are founded in no generally accepted structure. These philosophers believe that philosophical problems are merely "problems of linguistic usage, or of the meaning of words," (Popper, 2000b, pp. 13-15).

Others, arguing that philosophical problems are genuine problems, maintain that these are not only problems about words but that they are genuine philosophical problems about real things. Popper notes that "if by chance, they find themselves unable to accept any of the existing creeds, all they can do is to begin afresh from the beginning" (Popper, 2000b, p. 13). From this, we can see a difference between scientific and philosophical problems, in that science normally works within a general accepted structure functioning as an extension of general accepted knowledge, while philosophy works from basic creeds.

I disagree with analytic's claim that there are no genuine philosophical problems. At least, I agree with Popper's example of the philosophical problem of cosmology: "I, however, believe that there is at least one philosophical problem in which all thinking men are interested. It is the problem of cosmology: the problem of understanding the world – including ourselves, and our knowledge, as parts of the world," (Popper, 2000b, p. 15). The problem of cosmology is undoubtedly genuine and it is the very crucial problem to which both science and philosophy seek solutions, inquiring into and hoping to discover the truth of the cosmos. From ancient times through to the present, philosophers have struggled with the problem of cosmology as one of their most critical challenges, attempting to uncover its truths. In addition, I would argue that philosophical problems are genuine inasmuch as they are related to our notions, our beliefs, our lives, and our world, all of which influence human life. How can we treat these problems as non-genuine as they involve our lives? How could we say that problems concerning our world or our lives are not genuine? Therefore, the conclusion of the analytic philosophers is untrue.

2.7 Philosophy of Science

While the aim of science is to construct models of the world through theories, the aim of the philosophy of science is to construct a model of science (Fetzer, 1993, p. xii). In other words, science proceeds by the discovery of theories and laws of nature, while philosophy considers what theories and laws are (Hausman, 1994, p. 10). Science seeks explanations of the world, trying to discover the principles of nature. The philosophy of science seeks an understanding of the foundations, principles, and methodologies that science uses in its inquiries, in its work of searching for truths about the world. Okasha thinks that "the principle task of the philosophy of science is to analyse the methods of enquiry used in the various sciences" (Okasha, 2002, p. 12). The philosophy of science differs from science in that science is the study of the world, whereas the philosophy of science is the study of scientific inquiry. Therefore, if science is the study of the world, then the philosophy of science is the study of the study of the world. The key object of study for philosophers of science is scientific methodologies, and that study has "grown out of an attempt to find out exactly what scientists do or ought to do" (Medawar 1974, p. 287). Shapere gives an analogy of the different interests of science and philosophy of science,

> Just as formal logic, ever since Aristotle, has been supposed to be concerned with the 'form' rather than with the 'content' of propositions and arguments, so also philosophy of science was to deal with the 'form' - the 'logical form' - of scientific statements rather than with their 'content'. (Shapere, 1981, p. 29)

The differences between science and philosophy of science are summarized in the following chart.

Science	Philosophy of Science
■ Aims to construct a model of the world. ■ Searches for explanations of the world. ■ Tries to discover theories and laws of the nature. ■ Utilizes inductive and/or deductive logic.	■ Aims to construct a model of science. ■ Searches for explanations of what theories and laws are. ■ Seeks an understanding of the foundations and methodologies that science uses in its inquiries seeking truths about the world. ■ Interested in the reliability of the logical forms utilized in scientific research.

Figure 2.3: Comparison of Science with Philosophy of Science

For example, as noted, scientific method includes both inductive and deductive logic, but scientists attend only to the empirical results of their experiments and tests, they never question whether their methodology, both inductive and deductive, is or is not valid. It is rather the task of philosophy to deal with this kind of issue. While science does not attend to the validity of the logical forms it utilizes, the philosophy of science emphasizes that as a major area of study. How can scientific knowledge be valid if the scientists apply invalid logical forms in their inquiries (Rosenberg, 2000, p. 4)?

Popper, as a philosopher of science, notes his intention to study the methods of empirical science. He states that

> A scientist, whether theorist or experimenter, puts forward statements, or systems of statements, and tests them step by step. In the field of the empirical sciences, more particularly, he constructs hypotheses, or systems of theories, and tests them against experience by observation and experiment.
>
> I suggest that it is the task of the logic of scientific discovery, or the logic of knowledge, to give a logical analysis of this procedure; that is, to analyse the method of the empirical sciences. (Popper, 2000b, p. 27)

According to Popper, epistemology, within the philosophy of science, must deal with scientific method. It is the task of the philosophy of science to formulate a theory of the methods that science utilizes in acquiring scientific knowledge. The philosophy of science inquires into the choice of methods that scientists use.

> The theory of method, in so far as it goes beyond the purely logical analysis of the relations between scientific statements, is concerned with the choice of methods – with decisions about the way in which scientific statements are to be dealt with. (Popper, 2000b, p. 49)

Two key concepts in the philosophy of science are "aim" and "method" (Salmon, 1992, p. 1). The philosophy of science undertakes to analyze and understand the aims and methods of science. A scientist's philosophy of science will govern his aims and the methods he uses in pursuing scientific knowledge. Therefore the philosophy of science is essential to scientific inquiry in that it paves the way for science. Appropriate methods will certainly contribute to the growth of knowledge, while inappropriate methods may lead to time wasted, or inefficiency of inquiry, and to misinterpretations, for example treating a theory as universal.

Another characterization of the philosophy of science and its scope has been proposed by Rosenberg (2000, p. 2). He refers to the philosophy of science as the sort of question to which science cannot give answers. Science has been separated from philosophy since the Greek period, but it did not take all forms of knowledge with it. Questions that science cannot answer, or does not know how to answer, are left to philosophy. Mainly, he holds that the philosophy of science has to deal with two sets of questions:

- "First, the questions that science – physical, biological, social, behavioral cannot answer now and perhaps may never be able to answer.
- "Second, the questions about why the sciences cannot answer the first lot of questions." (Rosenberg, 2000, p. 4)

Rosenberg's definitions imply that science and philosophy are fully distinct and that it is the duty of philosophy to seek knowledge in areas where science cannot.

2.8 Philosophy of Science: Areas of Interest

What are the interests of the philosophy of science? Salmon suggests that there are three types of question that the philosophy of science must grapple with: (1) "the question just raised about the nature of scientific explanation", (2) "interesting questions about what it means to be a science and whether a single method is common to all sciences", and (3) the concern of "specific issues that arise in connection with particular fields of science" (Salmon et al., 1992, pp. 2-3). I have modified these somewhat to reflect my own thoughts, reclassifying Salmon's three types of question into four:

- Questions about the nature of scientific explanation
    - What are the aims of science?
    - How do scientists justify their claims? What constitutes scientific proof?
    - How does scientific knowledge advance and grow?
- Questions about scientific method
    - Is there a single standard method for all scientific inquiry?
        - Is it possible to give a general account of scientific methodology, or are there different methods and forms of explanation for various branches of science?
    - How do the physical, biological, and social sciences differ from one another?
- Questions about the scope of science, the difference between science and other disciplines.
    - The demarcation between scientific knowledge and other types of knowledge
    - The difference between facts and values
- Questions about specific issues that arise in connection with particular scientific fields.
    - Is medicine more an art than a science?

The growth of knowledge, the core interests of this study, is important topic in the philosophy of science. Although science analyzes many systems of knowledge of the world, these do not include the scope of science or of scientific interest. Therefore, the methodological disciplines that science uses to expand knowledge and the issue of the demarcation between science and non-science are left the philosophy of science.

The present study is related to the philosophy of science in terms of inquiry into the principles and methods of science, and of how to distinguish between science and non-science. As mentioned, Karl Popper's philosophy is central to my study of these issues. He argued for the principle of falsification as the most appropriate criterion of demarcation (Popper, 2000b, p. 40), and he believed that scientific knowledge has grown through falsification. Finding something wrong with, or falsifying, previous theory, is the essential method for bringing about scientific revolutions. He suggests that throughout the history of scientific development, falsification has been the most salient methodology leading to scientific revolutions (Popper, 1979, p. 258). The next chapter inquires into his philosophy of science, focusing especially on the principle of falsification and including some historical background of the concept.

Chapter 3

Karl Popper's Philosophy of Science

3.1 Fallibilism and Science

It may be noted that Karl Popper developed his philosophy of science from the notions of positivism. Popper's concept is not the same as, but is rather evolved from, positivism. Popperian and positivist concepts are related but often opposed to each other, as clearly seen in Popper's placing the principle of falsification in opposition to the positivist principle of verification.

Popper proposes the principle of falsification in place of positivism's principle of verification (Popper, 2000b, p. 40). His idea was to undercut the principle of verification and thereby to resolve the problems inherent in it. These two principles are situated on opposing sides of a balance position: one tries to verify; the other tries to falsify (Popper, 2000b, p. 41).

This most important concept grounds Popper's philosophy. He believes that the universal truth in scientific knowledge. Quine argues that Popper's concept is a negative methodology, a "negative doctrine of evidence", which is that, "evidence does not serve to support a hypothesis, but only to refute it," (Quine, 1974, p. 218).

According to Popper, every scientific theory is at all times subject to falsification. In other words, scientific knowledge is inherently fallible and subject to error; there is no certainty in science. Popper argued for "falsifiability solely as a criterion for the empirical character of a system of statements," (Popper, 2000b, p. 86). What he taught his students was that instead of trying to justify or uncritically believing the theories that had been handed down by authority, we should attempt to identify problems or mistakes in those theories, and then try to rectify them, leading us closer to the truth (Notturno, 2003, preface). Popper put it this way, "I may be wrong and you may be right, and by an effort, we may get nearer to the truth," (cited in Notturno, 2003, preface).

The real source of his advocacy of fallibilism is his critique of the inductive method to construct and support scientific theories. He denied that scientific theories could ever be justified as true. This position undercuts the ideas of many philosophers such as Wittgenstein, Carnap, Quine, Kuhn, Kant, Hume, and Descartes, who insisted that scientific knowledge required justification. For Hume, that justification was simply impossible and it is on this point that Popper differs from Hume. Popper recognized a problem with induction, similar to, but not identical with, the problem of induction as articulated by Hume (Notturno, 2003, p. 4). The problem of induction is elaborated in the next section.

3.2 The Problem of Induction

The problem of induction is "the question whether inductive inferences are justified" or "the question of the validity or the truth of universal statements which are based on experience, such as the hypotheses and theoretical systems of empirical sciences" (Popper, 2000b, p. 28). In brief, the problem of induction is that the inductive method may not be a workable tool for determining universal truths. This would seem to be in opposition to the method that scientists utilize in their research.

Inductive methods are typical of the methods that scientists utilize in their attempts to discover new knowledge. Science proceeds through the open-minded accumulation of observations. The scientist collects data from samples or experiments in an amount that he believes sufficient to justify the theory. The accumulation of repeated results from the sample one-by-one increases confidence in the theory explaining a certain natural law. The corroboration of theory is very important in supporting scientific knowledge (Singer, 1974, para. 43). From a certain number of samples, the theory will come to be accepted as a natural law which can be used to predict the results of any event or to explain anything that corresponds to the sample or experiment.

Popper disagreed with the use of inductive logic in scientific discovery and critiques the use of inductive inference in the pursuit of universal truths. He referred to those who advocate inductive logic as naïve empiricists (Popper, 2000b, p. 106). He disagreed with inductive methods, in that we cannot infer universal statements from singular statements. Universal statements cannot be inferred from experience. Rather, only singular statements can be inferred from experience. Though experimental results repeatedly confirm a hypothesis or theory, we cannot conclude that the hypothesis or theory is universally true. He argues:

> Now it is far from obvious, from a logical point of view, that we are justified in inferring universal statements from singular ones, no matter how numerous; for any conclusion drawn in this way may always turn out to be false: no matter how many instances of white swans we may have observed, this does not justify the conclusion that all swans are white. (Popper, 2000b, p. 27)

He added, emphasizing that induction can never be the road to universally true theories,

> Thus inference to theories, from singular statements which are "verified by experience" (whatever that may mean), is logically inadmissible. Theories are, therefore, never empirically verifiable. (Popper, 2000b, p. 40)

Scientific knowledge is based on empirical data obtained through experiments or other experience. It is impossible for us to experience all things and events in the space-and-time universe. A series of identical experimental results or observations cannot guarantee that we would get the same result or make the same observation in different times and places. This means that it is mistaken to conclude that a repeated experience validates a universal truth. Therefore, Popper argued that the knowledge we gain from experience can only be singular knowledge and that we cannot justifiably claim it as universal knowledge (Popper, 2000b, p. 28).

As time and space never repeat, how can we make universal truth claims? When time and space changes, all possibilities of result become open (Popper, 2000b, p. 62). That an experimental result is repeated again and again yields only probability not certainty. For example, most of us know that pure water boils at 100 degrees Celsius. That bit of knowledge, however only holds at sea level under certain conditions. If we perform an experiment to determine the boiling point of water on the top of a mountain high above sea level, the boiling point we observe will not conform to our ordinary understanding: it will be lower than 100 degrees Celsius. Thus a change of location can invalidate prior understanding, bringing what we thought we knew into question. From such deviant results, the scientist can analyze the defects in prior knowledge and generate new knowledge that explains the deviation.

Popper and Hume both argue that we cannot use inductive methods to prove the truth of a theory. That the sun has risen today does not guarantee that it will rise again tomorrow morning.

Universal statements are of the form "All S's are P's". How can we ensure that such statements are true, since we cannot observe all possible S's (Notturno, 2003, p. 17)? Universal statements are, according to Maurer, abstract statements that "transcend all observations" (Maurer, 2004, p. 2). Take, for example, the universal statement; "All crows are black"; is it possible for us to experience all the crows in the world? It is an impossible task to observe all crows throughout the world. So, how could we ensure there is not one non-black crow whose existence would make universal statement false? Even for an almost extinct species, for example, where there are only a few left in the world: how could we know that there are no animals of that species existing in other parts of the world, perhaps in the very deep of the forest where people rarely go? Hence, the inductive method cannot yield universal truths.

Normally, philosophers who do not believe in the possibility of the verification of universal scientific truths are skeptics like Hume. Popper, however, though he also rejected the possibility of verification of universal scientific knowledge, was no skeptic:

- While skepticism totally rejects scientific knowledge, Popper believes that we do have scientific knowledge.
- While skepticism requires verification for scientific knowledge, if there is to be such a thing, Popper argues that scientific knowledge does not require verification but rather testing against reason and experience (Notturno, 2003, p. 4).

Though Popper and Hume have the same point of view on the problem of induction, Popper criticized Hume for stumbling over the question how to obtain knowledge. For Popper, rejection of the inductive method for gaining knowledge created a problem for Hume. If inductive logic cannot lead to knowledge, how can we acquire it (Popper, 2000a, p. 45)? Popper discussed two possible answers to the question:

> (1) We obtain our knowledge by a non-inductive procedure. This answer would have allowed Hume to retain a form of rationalism. (2) We obtain our knowledge by repetition and induction, and therefore by a logically invalid and rationally unjustifiable procedure, so that all apparent knowledge is merely a kind of belief – belief based on habit. (Popper, 2000a, p. 45)

The second possible answer leads to the problem that the knowledge we gain from repeated experience is gained in a manner similar to the kind of induction that Hume entirely refuted (Popper, 2000a, pp. 45-46).

3.3 Induction and Probability

According to Popper, induction cannot be used to infer universal truths; rather the kind of knowledge we gain through induction is probable knowledge. Hence, inductive inferences are inferences of probabilities.

> So also, I fear, are those inherent in the doctrine, so widely current today, that inductive inference, although not 'strictly valid', can attain some degree of 'reliability' or of 'probability'. According to this doctrine, inductive inferences are 'probable inferences'. (Popper, 2000b, p. 29)

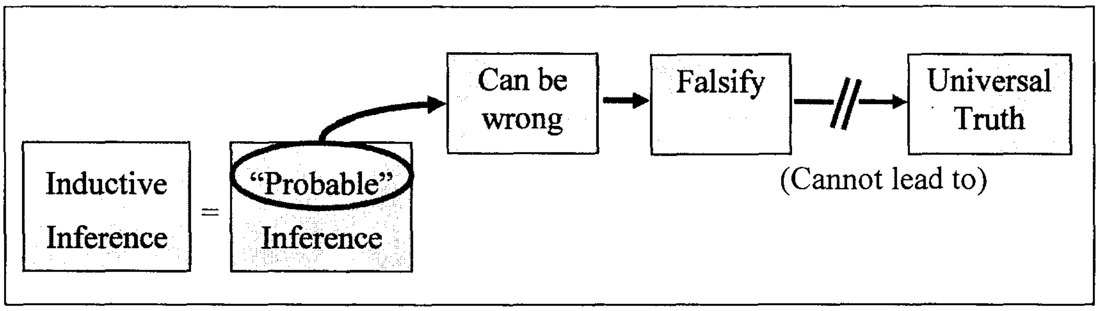


Figure 3.1: Inductive Inferences Cannot Lead to Universal Truths

Inductive logic cannot lead to universal truths. What it can lead to are continuous degrees of probability. Popper uses the word "corroboration" to express the idea that induction can be exploited in evaluating statements, even though it cannot prove statements to be true. He stated that:

> Theories are not verifiable [due to the problem of induction], but they can be "corroborated". The attempt has often been made to describe theories as being neither true nor false, but instead more or less probable. Inductive logic, more especially, has been developed as a logic which may ascribe not only the two values "true" and "false" to statements, but also degrees of probability. (Popper, 2000b, p. 251)

A higher degree of corroboration means a lower degree of falsifiability and a higher probability that the theory in question is universally true. The degree of corroboration increases as we find more corroborating instances (Popper, 2000b, p. 269).

Probability theory posits a continuum with truth and falsity as the upper and lower limits (Popper, 2000b, p. 30). When we obtain a positive result from a test of a theory, the probability that the theory is true is increased, meaning that we can be more confident in using it. Said differently, as the degree of corroboration increases, our evaluation of the theory approaches the upper probability limit, truth. We consider it more probably true. However, we can only justifiably claim greater confidence in the truth of a theory, never that we have proven it to be universally true. It is impossible to reach the upper limit, but we can approach it with higher degrees of probability.

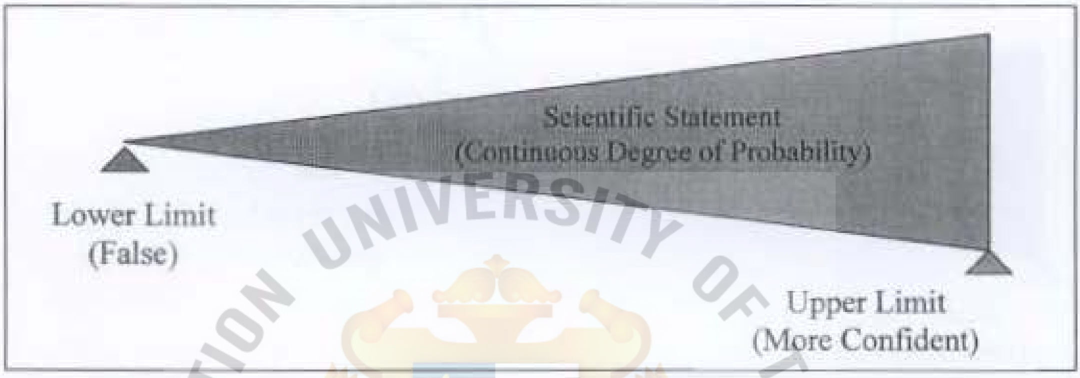


Figure 3.2: Probability Character of Scientific Statements

When we find something that contradicts a theory or prior knowledge, the theory is falsified, leading to another set of statements or new theory, which, in turn, must be tested to generate confidence in it as knowledge. The more positive results are accumulated in support of a theory the easier public acceptance of the theory will become.

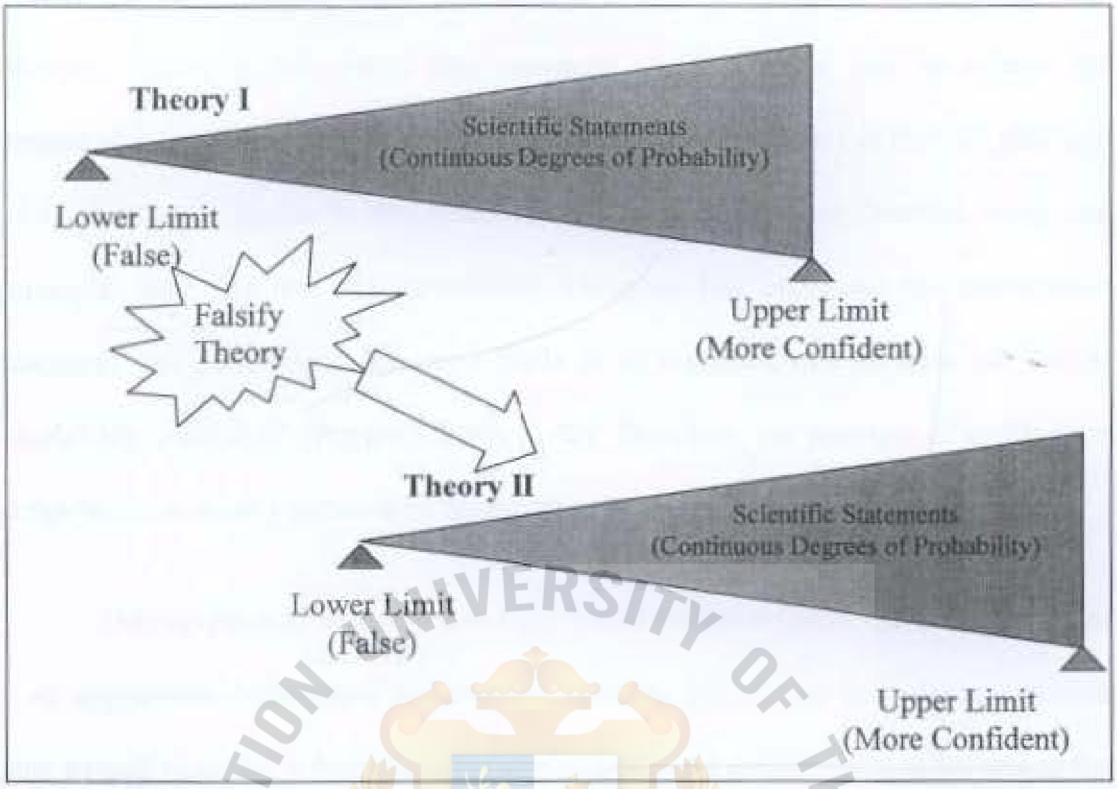


Figure 3.3: Probability Character of Scientific Statements and Falsification of Theory

3.4 Falsification as the Criterion of Demarcation

The problem of induction is that universal knowledge cannot be achieved through inductive methods, that we cannot verify the universal truth of knowledge. The consequence for Popper was that the principle of verification as the principle of demarcation must also be rejected. To reject verification as a tool in the search for scientific truth, is also to reject it as a criterion of demarcation between science and other endeavors.

For Popper, the two most fundamental problems for the philosophy of science are the problem of induction and the problem of demarcation. He clearly states that the problem of demarcation is "more fundamental". He argued that the basic reason scientists adhere to the inductive method as the main route to acquiring knowledge is "belief that this method alone can provide a suitable criterion of demarcation," (Popper, 2000b, p. 34). From this statement, it is obvious that he rejects the demarcation criterion proposed by logical positivism. A corollary is that the principle of verification is unable to demarcate science from non-science, because using that principle, both fall into the unverifiable category, that is to say the non-science category. The problem of induction leads us to conclude that theories are "never empirically verifiable" (Popper, 2000b, p. 40). Therefore, the principle of verification is not serviceable as a criterion of demarcation between science and metaphysics.

The rejection of the inductive logic based criterion forces the question: What is an appropriate criterion of demarcation between science and non-science? Popper also wished to define a distinction between science and metaphysics, as he ranked the problem of demarcation as the most fundamental. He resolved the problems of demarcation based on inductive logic, proposing a criterion that "allows us to admit to the domain of empirical science even statements which cannot be verified" (Popper, 2000b, p. 40). The principle of falsification is his solution.

To resolve the problem of demarcation raised by verificationism, he proposes the principle of falsification. Popper's proposal is diametrically opposed to that of logical positivism, for which a proposition is meaningful and scientific if-and-only-if it is either analytically or empirically verifiable. While logical positivists aimed to invalidate metaphysical propositions as meaningless, Popper argued that such an approach was entirely wrong. This is because the problem of induction suggests that there are no verifiable universal propositions, hence that scientific theories can never be verified by experience (Notturno, 2003, p. 17). In brief, we cannot use verification as the criteria for demarcation, because it is impossible, and indeed, it is not necessary, to verify universal statements.

Popper's exploitation of falsification is elegant in that, in his proposal, falsifiability can be used as the criterion of demarcation between science and non-science and because it is at the same time integral to the growth of scientific knowledge. Although scientific propositions cannot be verified due to the problem of induction, it is clear that they can be tested by experience in the sense that they can be falsified by the results of the test. Whereas verification cannot lead to universal truths, falsification can take us closer to truth, though it cannot achieve final confirmation that any given truth is universal. Science can grow through falsification. Falsification then plays its role as the common methodology used to acquire knowledge in science. Popper therefore suggests using falsifiability in place of verifiability as the criterion of demarcation (Popper, 2000b, p. 40). Any statement or theory that we can find a means of falsifying is a scientific statement or theory. On the other hand, any statement or theory that we can find no means of falsifying is not scientific. Falsification is an important characteristic of science. The refutability of a theory is a desirable attribute that classes it as scientific. He emphasizes that "A theory which is not refutable by any conceivable event is non-scientific. Irrefutability is not a virtue of a theory (as people often think) but a vice," (Popper, 2000a, p. 36).

It is widely thought that Popper developed the principle of falsification as the criterion of demarcation in direct response to the principle of verification. Popper himself claimed to have formulated the problem of demarcation, and the concept of falsifiability and testability as a criterion, in the autumn of 1919, before

Wittgenstein's concept of verifiability had come to be widely discussed in the Vienna Circle (Popper, 2000b, p. 312).

According to Popper, although we cannot fully verify a statement, we can decide conclusively whether any given scientific statement is false. In other words, to be scientific, a statement must be testable (Popper, 2000b, p. 40.). Consequently, instead of using verifiability as the criterion of the meaningfulness of statements, Popper proposes the criterion of falsifiability to make the distinction between scientific and non-scientific, especially metaphysical, theories. According to the principle of falsification, a statement is scientific if-and-only-if it is able "to be refuted by experience" (Popper, 2000b, p. 41). Although tests of a scientific statement cannot verify its truth, it is obvious that tests could show it to be false. This is because falsifiability is an attribute of science and is the standard method of scientific growth.

It is clear that the principle of falsification is better than the principle of verification to the extent that the principle of falsification resolves the problem that we cannot verify knowledge and that the principle of verification fails to make a distinction between science and non-science. While the problem of induction prevents us from verifying empirical propositions, it does not prohibit us from falsifying them. Stiver assesses Popper's ideas as closer to the actual practice of science than are the concepts of positivism (Stiver, 1996, p. 47).

In supporting the falsifiability criterion, Popper refers to a well-known remark of the great scientist Einstein: "In so far as a scientific statement speaks about reality, it must be falsifiable: and in so far as it is not falsifiable, it does not speak about reality," (cited in Popper, 2000b, p. 314).

Hence, falsifiability is an advancement over verifiability in that it has no trouble with the problem of induction. Moreover, according to Popper, the principle of falsification is able to demarcate science from non-science even for non-verifiable statements (Popper, 2000b, p. 40). Falsification, Popper notes, does not involve induction, but rather deduction by Modus Tollens, and therefore evades the problem of induction (Popper, 2000b, p. 41).

Falsifiability is a specific attribute of empirical statements. Among the various kinds statement, it is only empirical statements that can be falsified. Popper stated it clearly: "falsifiability solely as a criterion for the empirical character of a system of statements," (Popper, 2000b, p. 86). From this it can be inferred that, for Popper, science is empirical science:

Given Popper's criterion of demarcation,

'Falsifiability is an attribute of science'

From the above, we can infer that,

'Falsifiability is a characteristic only of empirical systems of statements,'

Therefore

'Scientific theories and statements are equivalent to empirical (systems of) statements' or, in other words, science is empirical science.

Kneale prefers Popper over the Positivists in that Popper did not treat metaphysical theory as meaningless (1974, p. 206). For Popper, it is impossible to verify the universality of knowledge, so that both scientific and metaphysical theories fall in the category of unverifiable systems of statements (Popper, 2000b, p. 40). If we adhere strictly to the principle of verification, both scientific and non-scientific statements are meaningless, as neither is verifiable. However, the principle of falsification can make the distinction, because scientific knowledge can be falsified. We know the means of falsifying scientific propositions. For example, given that the proposition "Water boils at 100 degree Celsius" would be falsified if we found water to boil at some other temperature, it is categorized with science.

On the other hand, statements for which we can find no method by which they could, in principle, be shown to be false are categorized as metaphysical statements. Take, for example, the propositions "There is God in the world", "There is ultimate reality in the world." We do not know how to falsify such propositions; we can find no way to test them and they are thus categorized as non-science.

Although falsifiability as a demarcation criterion is different from the logical positivists' principle of verification, Popper's intention is also to distinguish science from metaphysics, drawing a line between scientific and other kinds of theory (Kneale, 1974, p. 206). Popper declared his intentions early in *Conjectures and Refutations*, "My problem was different. I wished to distinguish between science and pseudo-science; knowing very well that science often errs, and that pseudo-science may happen to stumble on the truth," (2000a, p. 33).

From the above we may infer that scientific method involves attempts to falsify scientific propositions whenever we encounter the relevant experience. If the proposition survives efforts at falsification, the proposition is corroborated to a higher degree and we gain confidence in it. The more often a proposition survives attempts at falsification the higher the degree of confidence in that proposition. However, absolute certainty is unobtainable.

It must be added that Popper believes that any "scientific statement must be testable," (Popper, 2000b, p. 48). This does not mean that such statements have already passed the test. Rather a statement is scientific if there is a means of testing it, if it is able to be tested. Even though it may not yet have been tested, if there is a means of testing then it is a scientific statement. Those statements for which we find no means of testing are non-scientific.

Though Popper endeavored to demarcate science from metaphysics, he did not refute the importance of metaphysics, as it plays a certain role in epistemology. On the importance of metaphysics:

> From Thales to Einstein, from ancient atomism to Descartes' speculation about matter, from the speculations of Gilbert and Newton and Leibniz and Bocovic about forces to those of Faraday and Einstein about fields of forces, metaphysical ideas have shown the way. (Popper, 2000b, p. 19)

This is why Popper was so strongly opposed to the definition of meaningfulness advocated by the positivists. He criticized the main objective of logical positivism as being the eradication of metaphysics rather than the demarcation of science from non-science (Popper, 2000a, pp. 258-259). Although the positivist criterion of demarcation was refined by Carnap, from verifiability to testability or confirmability, the ultimate objectives remained unchanged. They continued to be a criteria of meaningfulness by which metaphysics would be "meaninglessness" (Popper, 2000a, pp. 273-274). Popper agreed that metaphysics is non-science; he did not agree that it is meaningless, because there are many examples of scientific knowledge having originated in mythology, cases in which metaphysics and myth later developed to include testable components (Popper, 2000a, p. 257). Popper refers to metaphysical theory as pre-science or pseudo-science (Popper, 2000a, p. 38).

3.5 Importance of Demarcation

As discussed in Chapter 2, one task of the philosophy of science is to study the methodology of scientific inquiry. That, in turn, is related to the choice of method. Science depends on choice in the search for knowledge. When a scientist conducts a scientific study, his inquiries have a certain aim, such as aiming to verify or to falsify a proposition. The choice of a method involves the aim of the inquiry. This choice is directly related to the criterion of demarcation:

> These decisions will of course depend in their turn upon the aim which we choose from among a number of possible aims. The decisions here proposed for laying down suitable rules for what I call the 'empirical method' is closely connected with my criterion of demarcation: I propose to adopt such rules as will ensure the testability of scientific statements; which is to say, their falsifiability. (Popper, 2000b, p. 49)

The criterion of demarcation is critical to scientific discovery, influencing the methods that scientists employ in their research. The criterion of demarcation to which a scientist adheres will govern his choice of method for acquiring knowledge. For example, positivists distinguish science from non-science by the criterion of verifiability: whatever is categorized as science must be verifiable; they would thus choose a method for verifying propositions. Verification here defines the method of inquiry. Those who agree with Popper, on the other hand, agree that falsifiability distinguishes science from non-science. It is certain that Popper suggests scientists to put their efforts into falsifying theory: "the method of science is the method of bold conjectures and ingenious and severe attempts to refute them," (Popper, 1979, p. 81).

The demarcation criterion defines the border between scientific knowledge and other forms of knowledge. It sets the frame for scientific inquiry. Scientists work on a particular project within the framework of science as demarcated by the criterion. The criterion of demarcation defines the territory of science and scientists conduct their activities within that territory.

To play the game of science one must follow the rules of the game, "Just as chess might be defined by the rules proper to it, so empirical science may be defined by means of its methodological rules," (Popper, 2000b, p. 54). The methodological rules of science are correlated to the criterion of demarcation, in that they must not conflict with it. Those players who break the rules are out of the game; or it may simply be said that they are not in the game of science. Falsifiability is utilized as the rule of demarcation between science and non-science. As Popper maintains, "it is only science which replaces the elimination of error in the violent struggle for life by non-violent rational criticism," (Popper, 1979, p. 84).

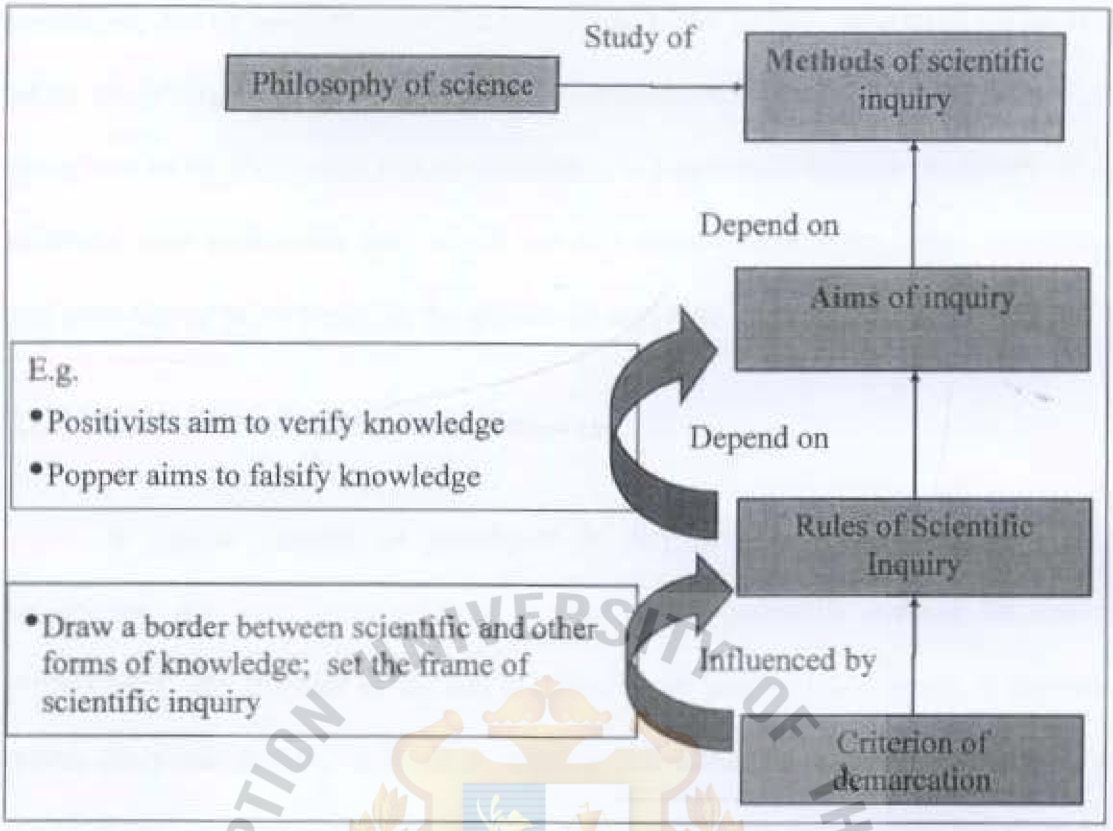


Figure 3.4: Popper's View of the Importance of Demarcation

Two methodological rules of science suggested by Popper are noted here. First, "The game of science is, in principle, without end," (Popper, 2000b, p. 53). This means that we will never arrive at the end of scientific knowledge. The search for scientific knowledge is continuous, inasmuch we can never claim the definite truth of any theory. Scientists should never stop at any specific level of knowledge. They should not give up the sense of endeavor in the search for better knowledge. If scientists were certain of the truth of theory, they would lose all inspiration to seek for betterment and scientific knowledge would not grow. The second rule of the scientific game is that good reason is required for rejecting a theory or hypothesis that has passed a test. In other words, we may not naively declare a theory false without good reason (Popper, 2000b, p. 54). A corollary of the first rule is the objection to positivism that its position on verification would make us lose motivation for seeking better knowledge. As positivism aims at verification, once that is successful - or thought to be so -there would be no motivation to improve or develop the theory. If all scientists were positivists, they would one day cease to search for better knowledge and there would be no room for the growth of scientific knowledge.

3.6 Deductive Logic in Scientific Discovery

A typical concept of positivism is that in order to discover scientific knowledge, inductive logic must be applied as the scientific method for testing propositions. The purpose of the test is to verify the proposition. Popper, in contrast, denies the possibility of verification, arguing that scientific testing and processes of trial and error process are indeed required, but with the aim not to verify but to falsify propositions (Popper, 1979, p. 81). Even though it is impossible to verify statements of the form, "All S's are P's", such statements are definitely open to falsification. If we could observe even one example contradicting such a statement, the statement is necessarily false.

Popper argues that deduction contributes to scientific discovery. According to him, scientific discovery begins with an element of inspiration. New ideas do not begin with logical reconstructions, but rather with an irrational element of creative intuition (Popper, 2000b, p. 30). When we experience a phenomenon, a new idea is generated from inspiration. It is not a rational element that provokes us to think of new idea, but rather creative intuition functions to trigger new ideas.

When a new idea has been triggered, it is then the turn of deduction to construct hypotheses. Hypotheses are formulated using deductive logic. The expected result is predicted based on deductive inference from current theories. Before doing an experiment, we normally have a set of expected results in mind. Where does the prediction of results come from? We do not start from a blank idea when formulating a hypothesis. We have at hand a body of prior knowledge and we deductively apply that knowledge to synthesize the hypothesis (Popper, 2000b, pp. 32-33).

After the hypothesis is formulated, then we proceed to test for the predicted results. The results can be either positive or negative. If the result is positive, the hypothesis and the theory from which we, at least partly, deduced it, passes the test for the time being (Popper, 2000b, p. 33). If the result is negative, then the hypothesis is falsified. That falsification also impacts the theory from which the hypothesis was deduced. This is how scientific inquiry can advance through deduction.

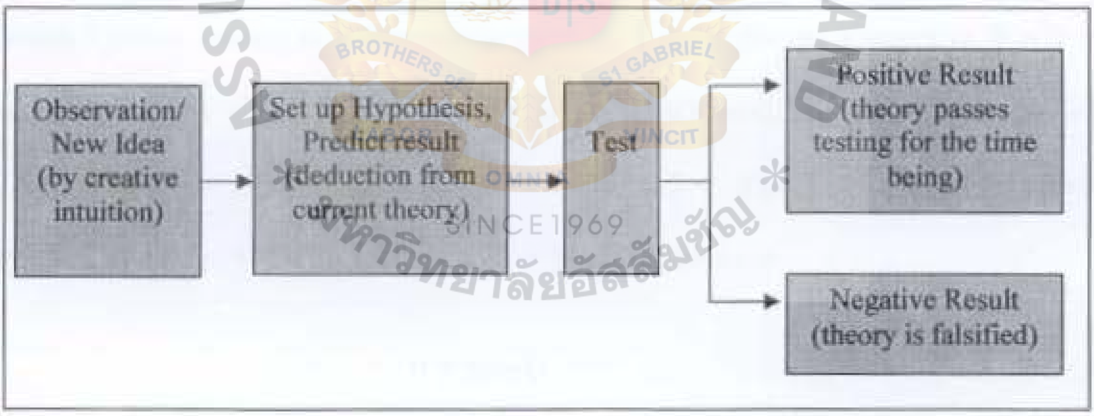


Figure 3.5: Deduction in Scientific Inquiry

It is important to emphasize that even though Popper suggested using deductive methods in testing scientific statements, deduction does not verify those statements (Popper, 2000b, p. 47). The notion that we cannot verify the truth of any statement overarches his philosophy of scientific inquiry. The test only helps us to make a decision whether to treat a statement as true or as false. Test results are particular, not universal, events. "For the time being" above means that, for Popper, although the results of a particular test are positive, there is no guarantee that they will be positive in the next test: "It should be noticed that a positive decision can only temporarily support the theory, for subsequent negative decisions may always overthrow it," (Popper, 2000b, p. 33).

3.7 The Logical Form of Falsification

The logical form of falsification as Popper articulates it is deductive. Falsification does not involve inductive but deductive logic: "the method of falsification presupposes no inductive inference, but only the tautological transformation of deductive logic whose validity is not in dispute" (Popper, 2000b, p. 42). A scientific theory is falsified, if a single experience contradicts it. This is the Modus Tollens deductive inference, invoked by Popper for the attempt to falsify a statement. A true singular statement can falsify a universal statement. This kind of logic is deduction proceeding in the inductive direction, from particular to universal (Popper, 2000b, p. 41). The logical form of Modus Tollens is:

If P then Q

~Q

Therefore ~P

Within this logical from, if we could find an example contradicting Q, then we would be justified in inferring that P is false. To falsify a statement, the inference that Popper employs with Modus Tollens recommends that we search for a counter-example of the statement at issue. As long as we find no contradicting phenomena, the statement survives the attempt at falsification.

For example,

Statement A: "All birds can fly"

If A is true, then every penguin can fly

Fact: penguins cannot fly

Therefore, statement A is not true

This example shows that if we would like to falsify a statement we should search for a counter-example of the statement, which, in this case would be, "not all birds can fly" or "there is at least one bird that cannot fly". As long as we find no counter-example, the statement A survives. However, if we do find a counter-example (we find a penguin that cannot fly) the statement has been falsified. Hence, for Popper, seeking a counter-example is critical for falsification.

However, a single counter-example is not enough to falsify a theory. To falsify an existing theory, or to accept a replacement theory, the contradicting occurrence must be reproducible. A non-reproducible single occurrence is not a strong enough reason for scientists to accept that falsification has occurred (Popper, 2000b, p. 86). When a scientist discovers an occurrence contradicting existing theory, either by coincidence or by intention, he does not immediately accept the new concept and falsify the old theory. Rather, he must reproduce the occurrence again and again to validate the contradicting results and to corroborate the falsification.

Consistency is an essential characteristic of any proposition. Popper believes that consistency is the most fundamental characteristic of any possible statement, whether empirical or non-empirical, whereas falsifiability is characteristic of empirical statements only, not of non-empirical statements. That is to say, a consistent statement need not be empirical (Popper, 2000b, p. 92).

Given the requirement for the consistency of contradicting occurrences, self-contradictory statements are not permissible for purposes of falsification as Popper describes it. This is because all self-contradictory statements can be shown to be false (Popper, 2000b, p. 91). In other words, there is no consistency in the contradicting occurrences of self-contradictory statements, or there is too much variety in the counter-example of self-contradictory statements.

3.8 The Principle of Causality

One of the most important concepts in science is the principle of causality, that an effect is explainable by causes. Conversely, if we know the causes, we can predict their consequences. Deductive prediction is a benefit of science. From existing knowledge, scientists can predict results from causes through deductive inference. However, as Popper rejects the universality of theory, or, at least, insists that every theory is subject to falsification, the principle of causality can provide only predictions of probabilities. If the principle of causality implied the universal necessity of the prediction, effects would definitely follow causes and the underlying theories would not be falsifiable. According to Popper's demarcation criteria, such certainty is not part of game of science, but rather of metaphysics (Popper, 2000b, p. 61).

Given a theoretical system that implies a certain conclusion, we could falsify the system by falsifying the conclusion. This is an application of Modus Tollens

(Popper, 2000b, p. 76). Consider, for instance, the statement "Water boils at 100 degrees Celsius"; the conclusion would be that if we heat water to 100 degree Celsius it will boil. Whenever we find that water does not boil at 100 degrees Celsius, we have falsified the conclusion by finding a contradictory event and the statement, "Water boils at 100 degree Celsius" is falsified along with the conclusion.

However, this does not mean that when we have found a counter-example to a theoretical system, the whole system has definitely been falsified. The whole system may not collapse, as it may be just part of the system that is false (Popper, 2000b, p. 72). The statement, "Water boils at 100 degrees Celsius" need not be totally rejected when we find water boiling at a different temperature. We need rather to adjust the statement to reconcile it with the inconsistent result. The statement, "Pure water boils at 100 degrees Celsius at normal sea-level atmospheric pressure" is an improvement over the earlier statement in that it takes into consideration the effects of atmospheric pressure and contamination.

3.9 Existential Statements and Probability Statements

Existential statements (for example, "There is a white raven") seem to stand in opposition to universal statements (for example, "All ravens are black"). The negation of a strictly universal statement is equivalent to a strictly existential statement (Popper, 2000b, p. 68). Thus in the above example, the negation of the universal statement "All birds can fly" is "Not all birds can fly" which is equivalent to the existential statement, "There is at least one bird that cannot fly" or "There exists a non-flying bird." Hence, the attempt to falsify a universal statement, the attempt to find a counter-example, is also the attempt to confirm an existential statement.

But while we validate an existential statement to falsify a universal statement, which implies that the universal statement is scientific as it is capable of falsification, the existential statement itself is not falsifiable. For example, the existential statement, "There exists at least one immortal living thing," cannot be falsified. Any attempt to falsify this statement would require exploring every living thing, an impossible task. Moreover, in the case of existential statements that are not restricted in time and space, verification is open everywhere and at every time, they are open only for verification, not for falsification. Therefore, if the principle of falsification is the criterion of demarcation, then existential statements are not empirical, scientific, but rather metaphysical statements (Popper, 2000b, p. 69). However, if the existential statement adds to an empirical system, it is possible for the system to remain falsifiable, maintaining its scientific character (Popper, 2000b, p. 70).

Probability statements bring out interesting issue for falsifiability as the criterion of demarcation. Given Popper's definitions, probability statements are rather non-science as they are not falsifiable. The reason is that no occurrence could contradict a probability statement, as such statements are open to all possible occurrences, whether corroborating or otherwise.

> Probability statements will not be falsifiable. Probability hypotheses do not rule out anything observable; probability estimates cannot contradict, or be contradicted by, a basic statement, …
>
> Probability hypotheses are unfalsifiable because their dimension is infinite. We should therefore really describe them as empirically uninformative, as void of empirical content (Popper, 2000b, p. 190).

Although probability statements fall into the non-science category, many scientists utilize them in their scientific investigations. Scientists predict consequences in terms of probability hypotheses which have a degree of probability close to 1 (1 being the highest degree of universality). How is it that probability hypotheses, which are non-falsifiable, thus non-science, are utilized in empirical science? Popper responds that, "probability statements, in so far as they are not falsifiable, are metaphysical and without empirical significance: and in so far as they are used as empirical statements they are used as falsifiable statements" (Popper, 2000b, p. 204). Popper indicates by the word "as" that although probability statements "are" actually metaphysical, not scientific, statements, they can also be used "as" empirical statements. Probability statements can serve as falsifiable statements because they fall between existential and universal statements, between a probability of 0 and 1 respectively. Scientists apply probability hypotheses that have a probability close to 1, but it is impossible for them to have a probability of 1. There must be at least a minute possibility of deviation from the majority (Popper, 2000b, pp. 192-196). Therefore, it is possible to rule out the consequences or to contradict the expectation, and that constitutes falsification.

3.10 Marx's Theory of History, Psychoanalysis and Astrology: Science or Non-science?

Popper maintains that Karl Marx's theory of history, the psychoanalytic theories of Freud and Alfred Adler, and astrology are not science as they fail to have the falsifiability characteristic, his principle of demarcation, in spite of the claims of the followers of these three disciplines that they are science. A common characteristic of these disciplines is the attempt confirm or verify theory, including finding means of explaining away any contradicting phenomena (Popper, 2000a, p. 35). This is a critical issue, defining these disciplines as non-science according to the principle of falsification.

In the earlier state of Marx's theory of history, predictions formulated from the theory could actually be testable or falsifiable. For example if we predict a social event such as the "coming social revolution", that prediction could be tested over time. However, the followers of Marx do not accept falsifications of the theory, and evade falsification by, "re-interpreted both the theory and the evidence in order to make them agree," (Popper, 2000a, p. 37). That is, they throw away the characteristic of falsifiability, making the theory, for Popper, non-scientific.

The psychoanalytic theories of Freud and Adler are obviously non-falsifiable. As these theories are involved with human behavior, it is hard to falsify them because, "there was no conceivable human behavior which could contradict them" (Popper, 2000a, p. 37), since human behavior is different from person to person. The theories were formulated from previous experience and confirmed through "clinical observation". Positive results from such observations are counted as additional confirmation. This process does not differ from that of astrology. Astrologers predict events and then wait and observe, hoping that observation will confirm the predictions. When they encounter an event deviating from their predictions, astrologers find an excuse for the deviation in order to validate their theory so that it will survive what would, in science, count as falsification (Popper, 2000a, p. 35).

The hypotheses that astrologers use as the basis for their predictions are derived from previous observations. Astrologers claim that astrology is a science, as their method is based on induction same as what scientists utilize (Popper, 2000a,

p. 256). But for Popper inductive logic is a major epistemological problem, as it cannot lead to verification. Therefore, psychoanalysis and astrology are similar in their methods of inquiry in that they cannot really test their expectations, their theories are not testable, and thus they are non-science. Popper added that psychoanalytic theories are rather comparable to myth (Popper, 2000a, p. 38).

3.11 The Growth of Scientific Knowledge

Along with its use as the principle of demarcation, the principle of falsification, contributes to the growth of scientific knowledge, according to Popper. This is an important benefit we could gain from the principle. Popper shifted the point of view from the earlier characterization of the search for truth in terms of verification, to a characterization in terms of the attempt to falsify. He suggested that, "We have learnt from our mistakes, and thereby added to our scientific knowledge," (Popper, 1985, p. 178-179). Knowledge progresses through success in falsification, finding mistakes. He argues that, "the growth of knowledge proceeds from old problems to new problems, by means of conjectures and refutations," (Popper, 1979, p. 258).

Putnam (1974, p. 238) critiqued Popper for proposing an approach that is contrary to the attempt to discover the correct idea. Lakatos (1974, p. 264) explains that it is a misunderstanding to think that Popper was not interested in searching for truth or that he treated the search for truth as an unscientific motive. In response to such misunderstandings, Popper argues that truth is still important and remains the aim of scientific inquiry. What he suggests is that, given the problem of induction, it is never justified to claim that truth has been achieved. He shifts the emphasis from the search for certainty, to scientific progress (Popper, 1974, p. 1002), and it is through falsification rather than verification that we can grow scientific knowledge. The more we falsify scientific knowledge the more we succeed in refining our understanding of the world, in consequence of which we come closer to the truth. Popper is very clear about his position on the importance of truth and its relation to falsification:

> On the other hand, I was very far from suggesting that we give up the search for truth: our critical discussions of theories are dominated by the idea of finding a true (or powerful) explanatory theory; and we do justify our preferences by an appeal to the idea of truth: truth plays the role of regulative idea. We test for truth by eliminating falsehood. (Popper, 1979, pp. 29-30)

For Popper, the growth of knowledge is an important issue for epistemology. It is the center of all epistemological problems. He magnifies the role of science in epistemology, claiming that, "the growth of knowledge can be studied best by studying the growth of scientific knowledge," (Popper, 2000b, p. 15). If science does not carry out its duty to grow knowledge, it will lose its attractiveness. Let us imagine that there was no change or growth of knowledge; all our knowledge would be exactly the same as that of our ancestors and would continue the same for our descendants; the scientific structure of knowledge would be static. What is the function of science for human beings? Science contributes nothing if it does not expand knowledge. We know now that the earth, and even the sun, is not at the center of the universe, because of the growth of scientific knowledge. We know many things about our lives and our world that are different from what the ancients believed. Therefore, it can be said that the growth of scientific knowledge has brought us today's world. This process, the growth of scientific knowledge, is endless and must continue towards better knowledge; it is what makes science live.

"False" and "wrong" are undesirable words in general. When people hear them they typically have negative feelings. No one likes to be told that he is wrong. We would much rather hear the words "true" and "right". Throughout the history of the development of human learning, we have sought for truth and rightness. The true and the right are the aims of knowledge. Psychologically, this may be the cause of our negative reactions to the words "false" and "wrong", as they seem opposed to the aims of knowledge and truth. The consequence is that many people close their minds to the fact that "false" or "wrong" can give us knowledge. "False" and "wrong" are not damned devilish things, but rather contribute a great deal to the growth of knowledge.

Popper suggests a different approach to others for dealing with a problem. Normally, scientists perform experiments, or test their proposed solutions, attempting to prove that their theories and hypotheses are true. When scientists do research, the objective is to defend their beliefs, to prove that their theories and hypotheses are valid and true. Popper's approach is just the opposite. What we should do, he suggests, is not to attempt to prove, or validate, our proposed solutions, but rather attempt to falsify them, "whenever we propose a solution to a problem, we ought to try as hard as we can to overthrow our solution, rather than defend it," (Popper, 2000b, p. 16). He criticizes those scientists who adhere to prior theories as hardly likely to succeed in making discoveries (Popper, 1981, pp. 87-88), because such adherence could mislead them and conceal new discoveries from them.

For Popper, reality is accessed in layers. What appears to us ordinarily is the outermost layer. It is the task of scientists to inquire by conjectures into the inner layer of reality and try to improve knowledge by finding mistakes in our understanding of the outermost layer, scrutinizing into the inner layer of truth (Popper, 1974, p. 980). To grow knowledge we must seek out falsehood and eliminate it (Popper, 1979, pp. 260-261). The more we eliminate falsehood the more successful we will be in growing knowledge.

Therefore, instead of loathing mistakes, Popper suggests that, "we can learn from mistakes," (Popper, 2000a, p. vii). Scientific knowledge grows through the process of "conjecture" and "refutation". In growing scientific knowledge, scientists propose tentative solutions or anticipate by guesses, or conjectures. The conjecture is influenced by attempts to refute existing knowledge. Therefore, scientists should emphasize the endeavor to refute theory, seeking for mistakes and trying to understand problems. Success in refutation of a theory will bring us closer to the truth, as we could then correct mistaken points of the theory. More refutation brings us nearer to the truth (Popper, 2000a, p. vii-ix).

Popper does not deny the accidental discovery, but believes that this kind of discovery is rare, especially as compared to discovery through the process of falsification. After a scientist finds an example or a result of experiment that does not conform to existing theory, inquiry for better theory begins:

> What compels the theories to search for a better theory, in these cases, is almost always the experimental falsification of a theory, so far accepted and corroborated: it is, again, the outcome of the tests guided by theory. ....

Accidental discoveries occur too, of course, but they are comparatively rare. (Popper, 2000b, p. 108)

In many cases, people feel ashamed when they are told that they are wrong. In my opinion, we should feel guilty when we intentionally do something that is *ethically* wrong, but *epistemologically*, in the search for knowledge, it is not entirely bad when we find that something we have believed is wrong; rather that should elevate us to a higher level of knowledge.

I agree that the ultimate aim of learning is the pursuit of truth. But the issue is the methodology of pursuit, how we may achieve the truth for which we are searching. Most branches of knowledge have a propensity to think positively, to prove knowledge by trying to prove that arguments are true, especially scientific knowledge. In fact, the methodologies for proving a theory include both direct confirmation of the fact and indirect confirmation through the refutation of a fact which is contrary to the one we hope to confirm.

The knowledge we infer from finding something wrong contributes more than the knowledge that we gain from the confirmation of a theory. If we open our minds and consider past experiences, we will realize that throughout our lives we have learned a great deal from what is wrong. In real life, the ethical, political, and epistemological aspects of ordinary life are affected by occurrences that are related to wrong activities or wrong beliefs which come to be imprinted on our minds, though we would rather forget them.

Following Popper's treatment of the principle of falsification and the problem of induction, scientific theory cannot be verified, but rather can only be falsified

(Popper, 2000b, pp. 40-42). All tests, then, aim to falsify prior theory. In other words, whenever we falsify a theory or are successful in attempted refutation, we achieve the goal of the test and that contributes to a great moment of scientific discovery.

According to Popper, scientific progress is essential to scientific knowledge. He argues that scientific progress is a necessity for maintaining the rational and empirical character of scientific knowledge, "...if science ceases to grow it must lose that character. It is the way of its growth which makes science rational and empirical," (Popper, 2000a, p. 215).

According to Popper, knowledge grows through an infinite process of trial and error, "Knowledge cannot ... be the result of observation; it must, rather, be the result of an evolution of observation by trial and error," (Popper, 1999a, p. 63).

In order to grow knowledge, we must critically test our conjectures or guesses of what the result of the test will be. The results of testing can come out in two ways.

1. If the theories we test survive attempts at refutation, they gain in "verisimilitude" or "truthlikeness", which means that they approach the truth (Popper, 2000a, p. 219). However, because of the problem of induction, no matter how many times a conjecture or a theory survives refutation attempts, we cannot definitely conclude that it is universally true. We can only say that the more tests the conjecture survives the closer it is to the truth; it gains a higher "degree of truth-value" (Popper, 2000a, p. 397), but can never definitely be established as universal knowledge.

2. If the theories we test do not survive attempted refutation, that is, if we are successful in refuting them, then a scientific revolution occurs. From Popper's perspective, given that we can never achieve the absolute truth of scientific knowledge (Popper, 2000b, pp. 27-30), and using falsifiability as the demarcation between science and non-science, we can infer that scientific revolutions can occur at any time. All scientific knowledge has falsifiability as its distinguishing characteristic (Popper, 2000b, pp. 40-42).

In *Conjectures and Refutations*, Popper clearly emphasizes that the successful refutation of a theory contributes to scientific revolution, and treated confirmative results of tests of theory as inferior to refutation:

> …it is not the accumulation of observations which I have in mind when I speak of the growth of scientific knowledge, but the repeated overthrow of scientific theories and their replacement by better or more satisfactory ones. (Popper, 2000a, p. 215)

3.12 Verisimilitude

Some have misunderstood Popper's recommendation that we search for the mistakes in theory rather than for secure and certain knowledge to mean that he is not interested in truth. These critics have labeled his school of thought "negativism". It must be made clear that Popper's ideas do not suggest that we should cease to search for the truth. On the contrary, he emphasizes the search for truth, but advocates doing so in the negative manner of finding and eliminating mistake in existing theory. To the extent that we eliminate mistakes, we come that much nearer the truth.

Again, the problem of induction shows that we can never achieve certainty as regards what is true. Does Popper then fall into absurdity in recommending that we search for truth? Is he directing us towards an unachievable goal? Popper explains that what he recommends is the search for "interesting and relevant truth", that is, truth "which has a high degree of explanatory power." He believes that though we wish to attain universal truths, in fact we can attain only "relevant truths" through the process of conjecture, even though that relevant truth may later be falsified (Popper, 2000a, p. 229-230).

According to Popper, we cannot know how far our knowledge is from the truth. Nonetheless, in a comparative sense, we can judge whether what we know has come closer to the truth. Through consideration of their explanatory power, we can judge which of several competing theories is closer to the truth. In order to judge theory T_2 as closer to the truth than theory T_1, Popper (Popper, 2000a, 232) suggests six criteria:

(1) T_2 makes more precise assertions than T_1, and these more precise assertions stand up to more precise tests.

(2) T_2 takes account of, and explains, more facts than does T_1 (which includes, for example, the first criterion, that, other things being equal, T_2's assertions are more precise than T_1's).

(3) T_2 describes, or explains, the facts in more detail than does T_1.

(4) T_2 has passed tests that T_1 has failed to pass.

(5) T_2 has suggested new experimental tests, not considered before T_2 was formulated, and not suggested by T_1 (perhaps not even applicable to T_1), and T_2 has passed these tests.

(6) T_2 unifies or connects various hitherto unrelated problems.

In summary, a theory T_2 supersedes T_1 when it gains more true empirical content and/or has more explanatory power than T_1. This is the degree of "verisimilitude" that Popper uses to judge which theory is more advanced than others.

By "verisimilitude" Popper means the extent to which a theory is like the truth. It may be defined as the "truthlikeness" of a theory. He uses "degree of verisimilitude" to mean "degree of better (or worse) correspondence to truth or of greater (or less) likeness or similarity to truth." We can measure the degree of verisimilitude of a theory by assessing its true empirical content. A theory with a greater number of truth-contents has higher degree of verisimilitude. This means that it has a greater likeness to the truth (Popper, 2000a, p. 233). It must be noted that the verisimilitude is different from probability. The degree of probability refers to levels of certainty, how likely it is that a given statement is true (or false). A higher degree of probability means that we have greater confidence that the statement is true. The degree of verisimilitude, on the other hand, is an estimation of which among competing theories is more like the truth (Popper, 2000a, p. 236-237).

The concept of verisimilitude has to do with the comparison of the truthlikeness of multiple theories and the consequent judgment which has the greatest likeness to the truth. A greater degree of verisimilitude, greater truth-content, implies that the theory is more advanced than those with less truth-content or with more false-content. From this it may be inferred that it is not necessary to radically falsify an entire theory in order to realize scientific progress. If only a few adjustments to a theory lifts its explanatory power and gives it more truth-content, in terms of the six criteria listed above, that constitutes growth in scientific knowledge, in Poppers estimation.

Chapter 4

Critiques of the Principle of Falsification

4.1 Thomas Kuhn

The philosophy of science developed by Thomas Kuhn is not entirely different from that of Karl Popper, rather there is a certain degree of similarity between them, in particular as concerns the search for knowledge. Kuhn: "Sir Karl's view of science and my own are very nearly identical. We are both concerned with the dynamic process by which scientific knowledge is acquired," (Kuhn, 2004, p. 235). However, in detail, Kuhn disagreed with Popper on how scientific knowledge grows, specifically, with Popper's insistence that scientific knowledge grows through successful falsification. According to Popper, scientific progress can occur at any moment, as falsification is characteristic of scientific knowledge. He argues, "It must be possible for an empirical scientific system to be refuted by experience," (Popper, 2000b, p. 41). Scientific knowledge for Popper lives in an open world. Kuhn does not agree that the world of scientific knowledge is open. For Kuhn, that world is rather closed and scientific revolutions are very difficult and rare occurrences (Kuhn, 1970, pp. 64-65).

Kuhn introduced the concept of paradigm as central to his philosophy of science and argued that in the scientific world, scientific progress, or scientific revolution, happens when there is a "paradigm shift" in the scientific community. A paradigm describes a consensus on a body of knowledge by the scientific community. In any given period, there is a set of notions that govern scientific knowledge and the way that scientists view nature. This set of notions is called a paradigm, and the scientific community accepts them by consensus as the foundation of knowledge. All theories, hypotheses, notions, and statements are grounded in, or at least consistent with, the paradigm. All past examples and phenomena are explained within the paradigm. When scientists predict future phenomena, they do so in terms of, and governed by, the paradigm. The paradigm that governs scientists' view of nature at any time Kuhn calls the "normal paradigm". The normal paradigm, or normal science, is the paradigm that gives better answers to problems than any other paradigm at any particular moment (Kuhn, 1970, pp. 10-42).

Barbour expressed support for Kuhn's point that the normal paradigm dominates current knowledge, maintaining that observations are theory-laden, that is, influenced by theories, emphasizing that, "there simply is no theory-free observational language. Theories influence observations in many ways," (Barbour, 1997, p. 108). In other words, data collected through observation are influenced by the dominant paradigm. When we make an observation, the ways we understand and interpret, and even the questions we ask about it, are influenced by the body of knowledge to which we currently hold, the normal paradigm. Given these considerations, Kuhn argued that Popperian falsification is not free of the normal paradigm that one is attempting to reject. "The points to test and the manner of testing" in any attempt to falsify existing theory has the existing theory itself, the normal paradigm, as its fundamental concept (Kuhn, 2004, p. 239).

Popper disagreed with Kuhn's concept of normal science, arguing that it is "a danger of science". Normal science he wrote is the "routine of puzzle solving," (Popper, 1974, p. 1145). If the community clings to the routine of problem solving, that would bring "the end of science." Popper wrote:

> But "routine" may well take over, may completely supersede science. This is a danger to which I was blind before Kuhn opened my eyes. We may soon move into a period where Kuhn's criterion of a science – a community of workers held together by a routine – becomes accepted in practice. If so, this will be the end of science as I see it. (Popper, 1974, p. 1146)

Kuhn approached the development of scientific knowledge through the study of the history of science. He argued that science does not develop in a cumulative manner, "Perhaps science does not develop by the accumulation of individual discoveries and inventions," (Kuhn, 1970, p. 2). Rather, it is transformations from the normal paradigm to another paradigm, paradigm shifts, that contribute to the development of science: "successive transition from one paradigm to another via revolution is the usual development pattern of mature science," (Kuhn, 1970, p. 12).

Kuhn criticizes the principle of falsification, arguing that there is no falsification in science. Nevertheless, some of Kuhn's concepts are similar to Popper's concept of falsification, especially Kuhn's notion of anomaly. Kuhn questions the existence of falsification: "anomalous experiences may not be identified with falsifying ones. Indeed, I doubt that the latter exist," (Kuhn, 1970, p. 146). Kuhn argues that when we find an anomaly and make ad hoc modifications to theory, that does not constitute falsification (Kuhn, 1970, p. 78). The argument is supported by Maxwell who states, "Since theories may be "saved" by qualifying assumptions such as ad hoc hypotheses, conclusive falsifiability is not required," (Maxwell, 1974, p. 293).

For Kuhn, finding a small defect in an existing theory, does not mean that the existing theory is falsified, but rather that we have discovered an "incompleteness and imperfection" of the theory at a certain moment. He further criticizes the principle of falsification by arguing that, "if any and every failure to fit were ground for theory rejection, all theories ought to be rejected at all the time," (Kuhn, 1970, p. 146). Therefore, according to Kuhn, in the realm of science, there is no falsification. Ad hoc modification is the method of making any given theory more complete. This position, that there is no falsification in science, if correct, poses the problem for the principle of falsification that it is invalid.

Scientific advance begins with competition between an alternative paradigm and the normal paradigm, according to Kuhn. "The early developmental stages of most sciences have been characterized by continual competition between a number of distinct views of nature, each partially derived from, and all roughly compatible with, the dictates of scientific observation and method," (Kuhn, 1970, p. 4). This statement tells us that, for Kuhn, the initiating condition for the development of science is combat between the normal paradigm and a new competing paradigm. The new competing paradigm is formulated to explain observations that conflict with the normal paradigm. In other words, phenomena have been observed that the normal paradigm cannot account for. We may say simply that the normal paradigm fails to explain the observation. The conflicting observation here is not different from the counter-example in Popper theory. Hence, the situation described by Kuhn here is not different from what Popper describes as falsification.

Kuhn argues that "anomalies" initiate scientific discovery. "Discovery commences with the awareness of anomaly, i.e., with the recognition that nature has somehow violated the paradigm-induced expectations that govern normal science," (Kuhn, 1970, pp. 52-53). It seems to me that "anomaly" is the same as "counter-example", in breaking with "existing theory" or the "normal paradigm". According to Kuhn, an anomaly occurs when we find an example or examples that violate the normal paradigm, and that this is the beginning of a paradigm shift. According to Popper, we experience a counter-example when we find an example that contradicts existing theory, or, in other words, an example that the theory fails to explain (Popper, 2000b, p. 40). But then, Kuhn's "anomaly" and Popper's "counter-example" would seem to have the same meaning. Both refer to examples that contradict existing scientific theory, and both are originating points for scientific discovery.

An anomaly is able to shake the scientific community, threatening the normal paradigm. When an anomaly has been discovered, the scientific community goes into crisis, the normal paradigm is challenged by the anomaly and combat between the existing paradigm and the new one begins (Kuhn, 1970, pp. 66-76).

It is not easy to succeed in making scientific discoveries. It is not all anomalies that can affect normal science. Every new discovery encounters resistance from the old paradigm, but once the new paradigm defeats the old normal paradigm, a scientific revolution has occurred. Kuhn maintains that when an emerging idea developed in response to an anomaly threatens the normal paradigm of the scientific community, there are three possible ways in which that community responds to the crisis (Kuhn, 1970, p. 84).

First, the community does not accept the new idea; prior notions continually play a governing role in the scientific community. In this case, the community holds to the old paradigm and scientific knowledge does not change.

Second, the emerging idea has more critical power than in the first case but cannot defeat the old idea. Even though the new notion does not gain the consensual acceptance of the community, it is not totally rejected. New methodologies or evidence, such as newly developed tools, are required to assist the community in making a decision so as to select which idea should be adopted. This situation is one of struggle and eventually the community will return to the old paradigm.

The third case is the only one that brings scientific revolution. The new idea is successful in defeating the old idea. The new idea gains the consensus of the scientific community, becomes the new normal paradigm, and the old paradigm is discarded. In the first and second cases, nothing finally happens to the scientific community, the old paradigm continues to play the key role. Only the third case has significant impact on the community. The community changes its consensus from the old paradigm to the new paradigm. Kuhn calls this a paradigm shift or a scientific revolution.

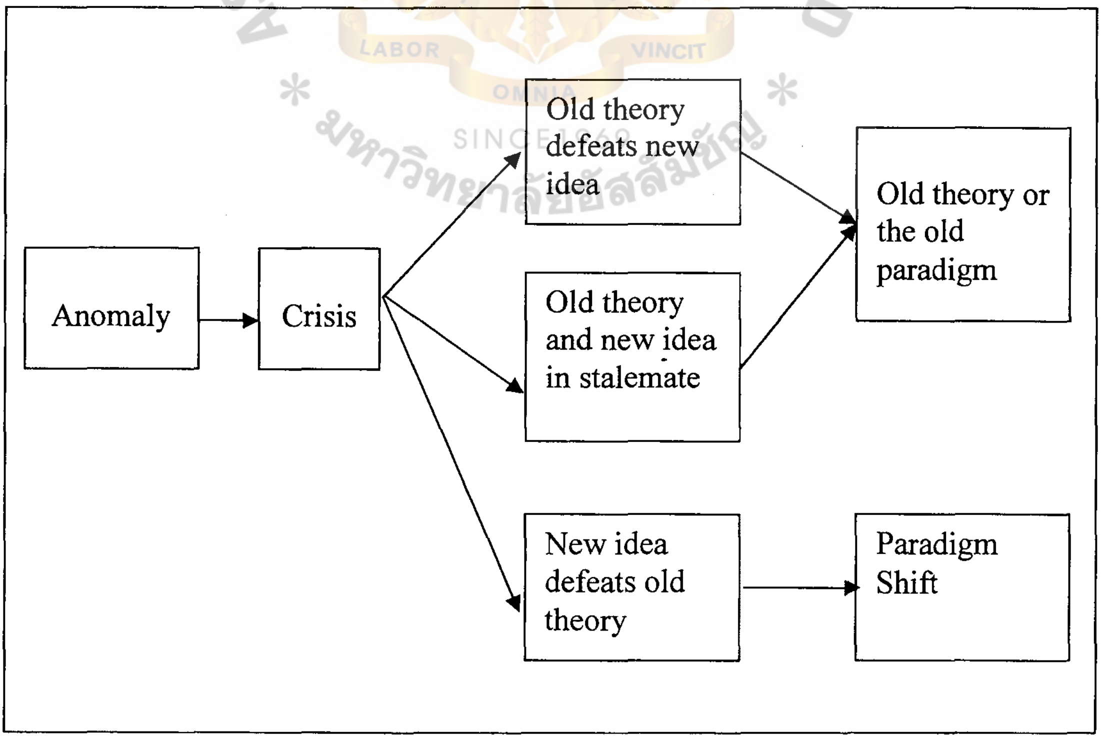


Figure 4.1: Scientific Revolution (Kuhn)

From this perspective, scientific revolutions are difficult and rare. Scientific knowledge, in Kuhn's view, constitutes a closed world, the normal paradigm adopted by consensus.

It is rare in the history of science, according to Kuhn, that a new notion has successfully conquered an existing one and become the new normal science (Kuhn, 1970, pp. 64-65). Crises are always resisted by existing science. Kuhn argued that anomalies may not falsify existing knowledge, but rather lead to ad hoc modifications of existing theory. This process extends existing theory so as to accommodate the anomaly or counter-example. Therefore, according to Kuhn, this process does not falsify theory, as existing theory remains accepted as valid. It leads merely to modification (Kuhn, 1970, p. 78).

This is a point at which that Kuhn differs with Popper. While Kuhn holds that it is very difficult to have a scientific revolution, Popper thinks that there is opportunity for scientific discovery and that existing theory is open to falsification at any time. Nonetheless, if we analyze these notions carefully, we see that they are the same in that they both recognize the opportunity of replacing existing theory by a new competing theory.

In response to Kuhn, Popper argues that scientific discoveries can occur every day. For Popper, not only major discoveries and major changes in the system are to be considered revolutionary. A discovery can be either major or minor. He suggests that minor discoveries are also revolutionary and that they happen more frequently than do the major discoveries. While major discoveries comparable to Kuhn's "paradigm shift", may be rare, minor discoveries occur every day. Popper argues that in real life, people may think and act differently from the "routine" influenced by "normal science" in order to resolve a problem or rectify an error in the system. This means that the growth of knowledge can occur at every moment, as people can always depart from routine (Popper, 1974, 1147). An example:

> The heating engineer who faces the problem of how to install a central heating system required to work under unusual conditions may just apply his established rules of thumb, and thus fail to solve the problem: in the face of this failure he may depart from his routine and (after eliminating several possible solutions) arrive at a critical solution of his problem. He will have acted as an applied scientist in my sense of the world, and he will have made a minor discovery by critical thinking, by the critical rejection of erroneous solutions. (Popper, 1974, p. 1147)

Contrasting Kuhn's and Popper's concept of revolution, Feyerabend prefers the latter as he believes that Kuhn "emphasizes the dogmatic, authoritarian, and narrow-minded features of normal science, the fact that it leads to a temporary 'closing of the mind', that the scientist participating in it 'largely ceases to be an explorer…'," (Feyerabend, 2004, p. 263). He adds further, "Let me now present in its entirely the picture of science which I think should replace Kuhn's account. This picture is the synthesis of the following two discoveries. First, it contains Popper's discovery that science is advanced by a critical discussion of alternative views," (Feyerabend, 2004, p. 267).

Putnam asserts that Popper and Kuhn differ on the issue of the falsifiability of scientific theory. Kuhn proposes that scientific theories can be immune to falsification while Popper argues that falsification is an intrinsic attribute of scientific theory (Putnam, 1974, p. 235).

Though Barbour suggests that all data are paradigm-dependent and that paradigm has certain degree of resistance to falsification by "modifying auxiliary assumption or introducing special ad hoc hypotheses", he does not insist that paradigms cannot be rejected (Barbour, 1997, p. 126). It is possible to overthrow a paradigm by the accumulation of unexplained anomalies. He summarizes, "paradigms are resistant to falsification by data, but data does cumulatively affect the acceptability of a paradigm," (Barbour, 1997, p. 127). Therefore, even the normal paradigm is potentially vulnerable to falsification or rejection.

I argue that Kuhn's concept of ad hoc modification, which he does not count as falsification, is not entirely different from Popper's concept of falsification. The anomaly or counter-example creates the need for ad hoc modification. In other words, existing scientific knowledge has failed to account for the anomaly, it has been falsified. Finding a counter-example to a theory opens the possibility of falsification. Moreover, as Kuhn himself asserts, "there is no such thing as research without counterinstances," (Kuhn, 1970, p. 79). Kuhn's notion is not different from falsification, as this statement emphasizes his belief that it is always possible to find a counter-example. For Popper, the counter-example is the aim of the attempt to falsify a theory, and the possibility of finding counter-examples is always open. He adds, "The growth of knowledge proceeds from old problems to new problems, by means of conjectures and refutations," (Popper, 1979, p. 258). Kuhn himself recognized the similarity of his model of scientific progress to Popper's,

> Both emphasize instead the revolutionary process by which an older theory is rejected and replaced by an incompatible new one: and both deeply underscore

the role played in this process by the older theory's occasional failure to meet challenges posed by logic, experiment, or observation. (Kuhn, 2004, p. 235)

Therefore, I argue what Kuhn advocates is, in fact, the same as what Popper calls falsification, Kuhn's scientific revolution or paradigm shift is no different from the falsification of a theory.

Similarities	Differences
o Emphasis on growth of scientific knowledge; progress of scientific knowledge very important - Popper: *The Logic of Scientific Discovery* - Kuhn: *The Structure of Scientific Revolutions*	o Popper: scientific progresses through "falsification" o Kuhn: scientific progresses through "paradigm shift" or "scientific revolution"
o Science progresses when a new theory defeats an old one	o Popper: science progresses through cumulative falsification. Falsification is possible at any moment. o Kuhn: paradigm shifts are very difficult; scientific revolutions rare.
o Progress is initiated by observations that existing theory fails to explain	o Popper: Science is falsifiable o Kuhn: There is no falsification in science
	o Popper: the counter-example – the example that contradicts existing theory o Kuhn: the anomaly that contradicts existing theory

Table 4.1: Popper and Kuhn: Similarities and Differences

4.2 Imre Lakatos

Lakatos accepts the principle of falsification in some respects while critiquing it in others. He rejects what he calls "naïve falsification" but accepts "sophisticated falsification" (Lakatos, 1995, p. 116). He defines the difference between naïve falsification and sophisticated falsification that:

> For the naïve falsificationist any theory which can be interpreted as experimentally falsifiable is "acceptable" or "scientific". For the sophisticated falsificationist a theory is "acceptable" or "scientific" only if it has corroborated excess empirical content over its predecessor (or rival), that is, only if it leads to the discovery of novel facts. (Lakatos, 1995, p. 116)

Naïve falsification means taking any counter-example as falsifying the theory. Lakatos rejects this approach, arguing that falsification should not be naively assumed based on any simple event (Lakatos, 1995, p. 121). That is, a counter-example or anomaly alone is insufficient for falsification. He writes, "The scientist lists anomalies, but, as long as his research programme sustains its momentum, ignores them," (Lakatos, 1974, p. 248). In other words, counter-examples do not falsify existing theory insofar as the anomalies are not strong enough to bring down the existing theory and the theory retains influence in the scientific community.

However, the rejection of naïve falsification does not entirely distance Lakatos from Popper. Popper also believes that theories should not be rejected too easily: "I found that, in addition, supersensitivity with respect to refuting criticism was just as dangerous. … He who gives up his theory too easily in the face of apparent refutation will never discover the possibilities inherent in his theory. There is room in science for debate," (Popper, 1974, p. 984).

Falsification, according to Lakatos, should refer to situations in which a theory or, what Lakatos called a "research programme", is falsified by another theory. Falsification occurs when the existing theory loses in the competition and is replaced by a new challenging theory. Existing theory is falsified when a rival theory achieves greater empirical corroboration (Lakatos, 1974, pp. 249-250). The prior theory has then been defeated by its rival. This is what Lakatos calls sophisticated falsification, "a sophisticated version which would give a new rationale of falsification and thereby rescue methodology and the idea of scientific progress. This is Popper's way, and the one I intend to follow," (Lakatos, 1995, p. 116).

This position, however, raises a problem for falsification as the criterion of demarcation. For Popper, the attempt to falsify a theory or statement is the attempt to find a counter-example, using the Modus Tollens logical form. But if naïve falsification is not really falsification, as argued by Lakatos, a counter-example does not count as falsification. That, in turn affects the ability of the falsifiability characteristic of science to demarcate it from non-science.

Popper responds that even though he was one of his students, Lakatos does not understand many of his ideas:

> It is for this very reason that I feel, unfortunately, obliged to warn the reader that Professor Lakatos has, nevertheless, misunderstood my theory of science; and that the series of long papers in which, in recent years, he has tried to act

as a guide to my writings and the history of my ideas is, I am sorry to say, unreliable and misleading. (Popper, 1974, 999)

In fact, Popper also emphasized empirical corroboration as part of the falsification of theory. For him, "a non-reproducible single occurrence", which has no corroborating occurrence, is insufficient for scientific study (Popper, 2000b, p. 86). He even insists that consistency is essential to any statement (Popper, 2000b, pp. 91-92). This can be interpreted to mean that Popper does not believe that a single occurrence of a counter-example would falsify a theory. To falsify a theory, there must be supporting corroborating counter-examples. Therefore, Lakatos' concept is not far from Popper's.

Like Popper and Kuhn, Lakatos is interested in the growth of scientific knowledge. While Kuhn places the word "paradigm" at the center of his philosophy, Lakatos uses the term "research program". While for Kuhn, science progresses when it accomplishes a "paradigm shift", changing from the old paradigm to a new one (Kuhn, 1970, p. 12), Lakatos argues that science grows through the progress of knowledge in scientific "research programs" (Lakatos, 1995, pp. 100-101). It would seem that the Kuhn's "paradigm" is close to Lakatos' "research program"; however, there is a major difference in that for Kuhn, the development of scientific knowledge through paradigm shifts is very difficult, a major leap in scientific knowledge from one paradigm to a better one, whereas, for Lakatos, development can come as a cumulative process of growth in scientific knowledge. A theory grows, for Lakatos, as its power of explaining real instances grows and as the content explainable by the research program increases (Lakatos, 1995, pp. 100-101). In other words, Lakatos's concept is that scientific knowledge progresses as theory becomes better in explaining phenomena that prior theory could not.

In the big picture, Popper, Kuhn, and Lakatos are similar in their concept of competition between currently accepted and rival theories. Scientific knowledge progresses when a new theory has conquered an old theory. However, they are different in the details, especially in the means by which such progress is achieved.

I would argue that Lakatos does not really differ from Popper in that both believe that science progresses when existing theory is brought down by a rival. He quite agrees with Popper that the power of falsification contributes more significantly to scientific knowledge than does the power of proof.

> The proving power of the intellect or the senses was questioned by the skeptics more than two thousand years ago; but they were browbeaten into confusion by the glory of Newtonian physics. Einstein's results again turned the tables and now very few philosophers or scientists still think that scientific knowledge is, or can be, proven knowledge. (Lakatos, 1995, pp. 91-92)

Nevertheless, there are differences in the details of falsification between Lakatos and Popper. As discussed above, Lakatos rejects naïve falsification because falsification is not an easy process. The question to be raised is: What is it when we encounter a counter-example if not falsification? For Lakatos, it is possible to have gradual progress even without successful sophisticated falsification. When a theory is challenged with a counter-example, the theory will be extended or readjusted to cover the counter-example. What is rejected is not the whole theory but "auxiliary hypotheses", while the core of the theory remains protected. The particular theory, or research program, survives, but its scope and/or explanatory power is extended by improving auxiliary hypotheses. For example, observations of the path of Uranus were found in 1843 to deviate somewhat from the path predicted by calculations using Newtonian theory. On the basis of those deviations, John Adam predicted the existence of another planet beyond Uranus. In 1846, Johann Galle proved the existence of such a planet and named it Neptune (S. Strickland & E. Strickland, 2006, p. 47). Lakatos also mentions this example of an apparent counter-example to Newtonian mechanics and the law of gravitation before they were challenged by Einstein's theory of relativity. For Lakatos, Newtonian theory was not thereby falsified. Rather, it had the power of established theory to resist falsification. It was finally discovered that the calculations based on Newtonian theory deviated from observations because there was a previously unknown planet, Neptune, which perturbed the path of the orbit. We would not want to call this falsification, but rather an improvement in knowledge, an enlargement of the explanatory power of the Newtonian theory (Lakatos, 1995, pp. 100-101).

Auxiliary assumptions or auxiliary hypotheses play a role in empirical testing and affect the interpretation of the results. Predictions based on a theory may fail to materialize in a test for them, but that does not necessarily mean that the theory has been falsified; it may rather be that auxiliary hypotheses were mistaken. Auxiliary hypotheses play a role in protecting the theory from the falsification. Stiver claimed that a weakness in Popper's concept of falsification is the difficulty in conclusively falsifying a hypothesis because there are usually alternative explanations for its failure under test (Stiver, 1996, p. 47).

For Lakatos, Newtonian theory is unfalsifiable, as he believed that it is impossible to make any observation that what would refute it (Lakatos, 1974, p. 246). In that case, Newtonian theory would be unfalsifiable, in the same way as Marxist theory is unfalsifiable, that is, anomalous observations are explained away rather than accepted as falsifying the theory; by Popper's criteria of demarcation, then, Newtonian theory would fall into the category of non-science (Okasha, 2002, p. 15).

Popper responds that Newtonian theory remains science in that it is indeed possible to find means of falsifying it. He maintains that Lakatos' notion that Newton's laws are unfalsifiable is "completely unacceptable," (Popper, 1974, p. 1007). He explains, "There is an infinite number of simple and quite different sets of possible observations (or potential falsifiers) which if accepted would refute Newtonian theory," (Popper, 1974, p. 1004). For example:

> Suppose that our astronomical observations were to show, from tomorrow on, that the velocity of the earth (which remains on its present geometrical path) was increasing, either in its daily or in its annual movement, while the other planets in the solar system proceeded as before. Or suppose that Mars started to move in a curve of the fourth power, instead of moving in an ellipse of power 2. Or assume, still more simply, that we construct a gun that fires ballistic missiles which consistently move in a clearly non-Newtonian tract .... There are an infinity of possibilities, and the realization of any of them would simply refute Newton's theory. (Popper, 1974, pp. 1004-1005)

One of the distinctive differences between Popper and Lakatos has to do with how scientific knowledge advances. Popper encouraged efforts to falsify theory because falsification leads to the development of scientific knowledge, while defending a theory does not really contribute to the growth of knowledge (Popper, 1979, pp. 29-30). Lakatos, on the other hand, believed that it is possible to grow knowledge through increasing the explanatory power of existing theory. The suggestion of improving theory via adjusting auxiliary hypotheses manifests his support of attempts to protect or defend a theory from the challenge of counter-examples (Lakatos, 1995, pp. 100-101).

Therefore, it can be inferred from Lakatos position that falsification does not, after all, demarcate science from non-science. He writes that the principle of falsification is "too narrow criterion of demarcation between scientific and non-scientific," (Lakatos, 1995, p. 97). For Popper, falsification is the aim of scientific inquiry, in other words, when a scientist is doing research, he is attempting to falsify a theory, as success in falsification means progress in scientific knowledge (Popper, 2000b, p. 49). Popper criticized the introduction of the concept of auxiliary hypotheses for attempts to protect theory from falsification as, "destroying, or at least lowering, its scientific status"; "the criterion of the scientific status of a theory is its falsifiability, or refutability, or testability," (Popper, 1993, p. 145).

But for Lakatos, not all scientific endeavor aims at falsifying theories. Protecting or defending a theory is, for him, also an important aim of scientific research. The growth of knowledge can proceed through the defense of theory by improving auxiliary hypotheses (Lakatos, 1995, pp. 100-101). This would imply that falsification is not the absolute aim of science, with the consequence that it cannot function as the demarcation criterion.

It is obvious that Lakatos supports sophisticated falsification and agrees that through it, knowledge progress. The emergence of a new research program is the consequence of success in falsifying a previous research program. The old research program will be replaced by the new one (Lakatos, 1995, p. 116).

In response to Lakatos' argument that existing theory resists falsification by adapting auxiliary components while retaining core content, I would argue that such a method of improving theory is not outside the boundary of falsification. Lakatos suggested that science can grow gradually through improving a theory's auxiliary components. A theory develops gradually as a series of theories, from T_1 to T_2 to T_3 and so on, as the theory is improved in response to counter-examples through the adaptation of auxiliary hypotheses (Lakatos, 1995, p. 114). I do not see that this methodology differs from falsification as Popper construed it. T_1, T_2, and T_3 are not exactly the same theory. T_1 is not T_2, and T_3 is neither. Even though they have the same core content and may differ but little, it has to be accepted at least that they are different in context. No matter how little we have adapted the auxiliary components of a theory, the theory has changed and is not the same as the prior theory. This is in line with Popper's reply to this critique in which he states, "If we falsify it, we falsify the whole system," (Popper, 1974, p. 982). When scientists accept the T_2 version, then T_1 is falsified. When the theory has developed to T_3, T_2 has lost to its successor. The development or pattern of improvement in a series of theories is what happens when the T_n version defeats or falsifies its ancestor T_{n-1}.

In the case of the inaccurate prediction of the path of Uranus calculated through Newtonian theory, the prediction was inaccurate because of the influence of an unknown planet; the theory was thus not falsified by the observation that contradicted the theory. The deviation was not because of the resistant power of Newtonian theory, but because the scientists had not included the full environment of the phenomena in their calculations. The deviation was due to the input data. The theory remained unchanged. However, the fact of the deviation led to discovery, not regarding Newtonian theory but regarding the "system of the world" (Popper, 1974, p. 986), the discovery of a previously unknown planet in our solar system. What was falsified was our understanding of solar system, according to which there were no planets beyond Uranus.

When a contradicting observation leads to adapting a theory, changing it from T_1 to T_2, that should count as falsification of the theory. In his study of growth models of scientific knowledge, Kneale analyses Popper's assertion that he was interested in the whole system of theory rather than in a number of separate sciences (Kneale, 2004, p. 441). Hence, if something fails in a theoretical system and that leads to improvement in a distinct part of the theory, the whole system will be affected and have to be improved as a whole.

For that reason, whenever we find an anomaly or counter-example, we know that at least something somewhere is mistaken. It is possible that the mistake is in the theory itself and it is possible that there is a problem with the data, such as limited data or insufficiently valid and reliable data. The former case could bring about falsification of the theory. The latter case, though it would not bring down the theory, could lead to a rectification of our understanding of the world, leading to a better understanding of actual phenomena.

4.3 Quine

Quine differs from Popper in arguing that we can never really test a single hypothesis or theory. In reality, the subject of the theory has a context, or environment. There are a great many factors surrounding a theory. In any empirical test, we are involved with a bundle of theories which is normally constituted of more than one. Hence, failure to achieve the predicted results in any test of a theory may not be because the theory is invalid, but because of other factors in the environment influencing the results. Therefore, we have to indentify the real culprit causing the failure (Quine, 1992, pp. 13-14). For instance, if we load a thread with weight exceeding its capacity, theoretically the thread will break. But if we encounter a case in which the thread does not break under these conditions, we need not conclude that the law or theory that predicted breakage has failed. There are many possible reasons that results may differ from predictions based on theory. There may be other forces, such as a nearby magnetic force, supporting the load so that not all the weight is directly on the thread. It may be the weight of the load is in fact not greater than the capacity of the thread; we may have miscalculated the weight because of a faulty scale. Lakatos (1995, pp. 184-185) refers to the Quine-Duhem thesis, which challenges the possibility of decisively testing a hypothesis as are too many extraneous reasons that could yield observations contrary to the theory. A failure to observe the predicted result does not mean that the theory has collapsed.

When we encounter a counter-example, according to Quine, that does not mean that the entire theory has collapsed. Rather, it may be that only a portion is mistaken and responsible for the anomaly. Therefore, we must separate those elements that are not threatened by the anomaly out from those that are. Only what remains, the elements threatened by the anomaly, must be rescinded. These remaining, false, elements would then be revised to comply with observations.

> Now some one or more of the sentences in S [set of truth] are going to have to be rescinded. We exempt some members of S from this threat on determining that the fateful implication still holds without their help. … Of the remaining members of S, we rescind one that seems most suspect, or least crucial to our overall theory. (Quine, 1992, p. 14)

With this method, Quine argues that we can protect the theory as a whole from falsification: "he construes holism as claiming that when a prediction fails, we can always save the threatened hypothesis by so revising the backlog of accepted theory that it, plus the threatened hypothesis, will imply the failure of the prediction," (Quine, 1992, p. 16).

In his book *Pursuit of Truth*, Quine formulates the problem of the indecisive situation when encountering a refuted result:

> The pair of observations in purported refutation of an observation categorical may be indecisive because of unforeseen indecision over the stimulus meaning of one of the pair of observation sentences. (Quine, 1992, p. 12)

Hempel supported this criticism of the falsifiability concept at the point of, "emphasis on the need for auxiliary hypotheses as additional premises in deriving testable consequences from theoretical hypotheses," (Hempel, 2001, pp. 367-368).

This does not mean that scientific theories are not falsifiable, or that they are always true. If we consider the system being tested as a bundle of theories, it is possible to falsify a scientific theory by failing to achieve predicted results. When an entire theoretical system cannot be used to make predictions because it fails to predict, this means, if we consider it as a whole, that the system, at least, is falsifiable.

I would argue that Quine's position is not wholly at odds with the principle of falsification as articulated by Popper. The thesis is similar to the Lakatos model of the growth of scientific knowledge. When faced with a counter-example the scientist tries to improve the theory, giving it more explanatory power so as to account for the counter-example. According to Quine, a theory is not entirely destroyed by the occurrence of counter-examples. It is rather that theory will be improved or repaired to make it better through improvement of the problematic elements (Quine, 1992, p. 16), which are, I suggest, the same as auxiliary hypotheses.

Like Lakatos' model, Quine's does not really contradict the principle of falsification, I argue. Repairing a theory means to correct misunderstandings or problems within the theory; that makes sense only if we acknowledge that the existing theory *has* misunderstandings or problems; existing theory is thus refuted, requiring improvement and replacement by a better theory.

> Duhem accepts the conventionalists' position that no physical theory ever crumbles merely under the weight of 'refutation', but claims that it still may crumble under the weight of 'continual repairs, and many tangled-up stays' when 'the worm-eaten columns' cannot support 'the tottering building' any longer; then the theory loses its original simplicity and has to be replaced. (Lakatos, 1995, p. 105)

According to Quine, auxiliary theories can be used to prevent falsification of the core theory (Quine, 1993, p. 14). However, the idea of adjusting a portion of a theory was already addressed by Popper. He wrote, "They make clear why the falsification of a logically deduced statement may sometimes not affect the whole system but only some part of it" (Popper, 2000b, p. 72). Hence, Quine's position does not really conflict with Popper's.

Popper responds to the idea of adjusting a part of a theory in order to protect its core from falsification by arguing that falsification of a part of a system impacts also the system as a whole,

> If we falsify it, we falsify the whole system. We may perhaps put the blame on one of its laws or the other. But this means only that we conjecture that a certain change in the system will free it from falsification; or in other words, that we conjecture the certain alternative system will be an improvement, a better approximation to the truth. (Popper, 1974, p. 982)

I agree with this. Even though we merely improve part of a theoretical system, perhaps referring to it as an auxiliary theory, and successfully retain what we refer to as the core theory, this means that at least some portion of the system has been changed. Given the improvement, the theoretical system is no longer identical to the old "bundle of theories". The old bundle has thus been falsified and replaced by a new one. Even where the core theory remains the same, the context has changed. Adjusting some part of a theory contributes to improved knowledge.

Quine's notorious concept of holism, one of the salient features of his philosophy (Quine, 1980, pp. 42-43), further supports my position on the applicability of falsification, and confirms that Quine's model is similar to the falsification model as a means of scientific progress. As scientific knowledge depends on experience, according to Quine, when we encounter any example that conflicts with theory we need to identify precisely what parts of the theory led to the anomaly. We must then readjust the problematic parts of the system. But by Quine's concept of holism, scientific knowledge is a matter of the whole, not the particulars. Quine argued that all parts of a whole system are logically interconnected.

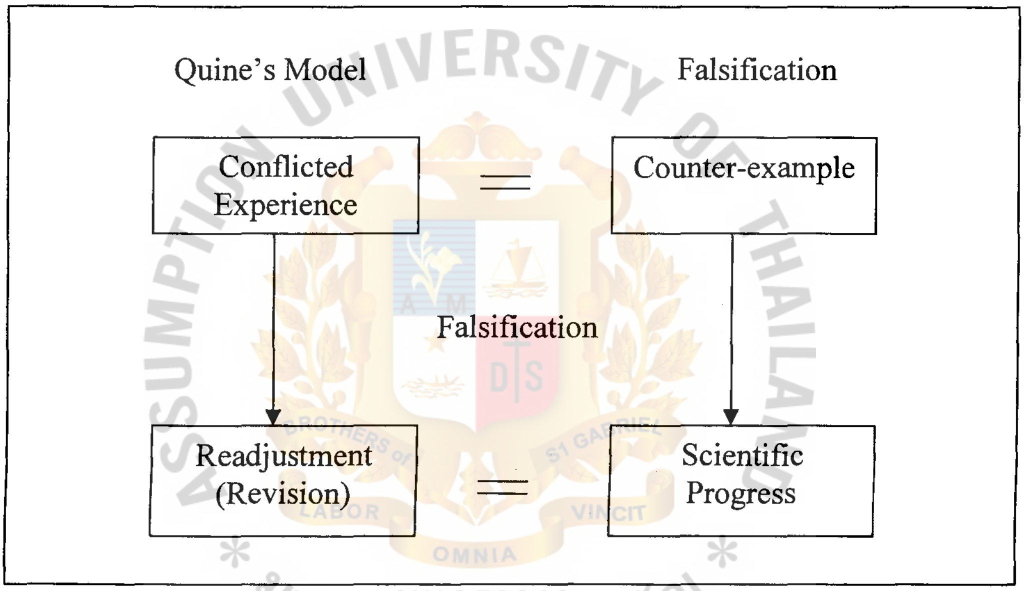
> A conflict with experience at the periphery occasions readjustments in the interior of the field. Truth values have to be redistributed over some of statements. Reevaluation of some statements entails reevaluation of others, because their logical interconnections. (Quine, 1980, p. 42)

Putting together Quine's holism and his approach to dealing with anomalies, we find that his concept is very close to the principle of falsification. Though the anomaly or counter-example may challenge only a part in the system, the concept of holism implies that the system as a whole is in trouble. Thus if we falsify part of a theory, the whole system is falsified. Quine expressed the importance of considering any system as a whole by saying that, "no particular experiences are linked with any particular statements in the interior of the field, except indirectly through considerations of equilibrium affecting the field as a whole," (Quine, 1980, p. 43).

Therefore if we do something to a certain part of the system, that affects the whole of the system. Readjustment of any part of the system affects the whole system. From this we may infer that if we reject or falsify some part of the system, the whole system has also been falsified. Even a few adjustment of the theory, the theory is not the same as the old one.

I would argue that Quine's position is not distinct from Popper's position on falsification. In *From a Logical Point of View, Nine Logico-Philosophical Essays*, he proposes an idea that I think does not differ from Popper's position on the falsifiability of scientific statements. Quine argues that all statements are open to "readjustment" or "revision".

> Even a statement very close to periphery can be held true in the fact of recalcitrant experience by pleading hallucination or by amending certain statements of the kind called logical laws. Conversely, by the same token, no statement is immune to revision. (Quine, 1980, p. 43)



Picture 4.2: Quine's Readjustment and Popper's Falsification

The readjustment or revision of any statement means that we have rejected, at least in part, the current statement. Only because the current statement has problems do we need to rectify it, otherwise it would not need readjustment. It requires revision to improve it and contribute to progress in scientific knowledge. The above figure displays the similarity between Quine's concept of the readjustment of a statement and Popper's model of scientific discovery. It is because of experiences that conflict with a statement that the statement requires readjustment, so as to make it able to account for the conflicting experience. The conflicting experience is not different from Popper's counter-example, and success in readjustment can be accommodated to the Popperian model scientific progress. Therefore, I argue that Quine's concept does not escape from that of falsification.

4.4 Paul Feyerabend

Feyerabend proposes the concept of "anarchism" in an epistemological context. He begins the introduction to his famous treatise *Against Method* with, "Science is an essentially anarchism enterprise". He argues that throughout the history of science, the progress of knowledge has not depended on one dogmatic method. There is no absolutely general law that applies to all scientific investigation. He expresses this idea forcefully through a question: "Are we really to believe that the naïve and simple-minded rules which methodologists take their guide and capable of accounting for such a 'maze of interaction'?" His answer to the question is "no" (Feyerabend, 2001, pp. 9-11).

The statement, "The events, procedures and results that constitute the sciences have no common structure; there are no elements that occur in every scientific investigation but are missing elsewhere," (Feyerabend, 2001, p. 1) conveys his criticism of all models that use methodological approach, whether, for example, falsification or verification, to demarcate science from non-science. The progress of science has no specific formal approach utilized only within the scientific community. All possible methodologies may be applied to a given scientific project depending on appropriateness. He argues that every scientific method has its own limitations, "There is not a single rule that remains valid under all circumstances and not a single agency to which appeal can always be made," (Feyerabend, 2001, p. 158). Different issues, different interests, and the different contents and contexts of scientific inquiries require different sets of approaches. The anarchistic epistemological characteristic proposed by Feyerabend certainly constitutes a challenge to Popper's philosophy of science.

Feyerabend's ideas are opposed to other philosophers of science. While many philosophers of science, such as the positivists, Popper, and Kuhn, praise the success of science and admire the progress of knowledge as the supreme objective of the scientific community, Feyerabend thinks differently. He writes, "To say: 'the procedure you used is non-scientific, therefore we cannot trust your results and cannot give you money for research' assumes that 'science' is successful and that it is successful because it uses uniform procedures," (Feyerabend, 2001, p. 2). This position is mistaken in two ways, according to Feyerabend, first in the assumption that science is always successful and second in the assumption that science uses uniform procedures of investigation. He argues that it is not the case that science always succeeds because there have been many instances of failure in science. He argues that science has no uniform approach as there is no single procedure that could be applied to every problem (Feyerabend, 2001, p. 2).

The latter argument obviously contradicts Popper's position on falsification. Popper thinks that falsification is or can be construed as the uniform procedure of scientific investigation and that why he suggests falsifiability as the criterion of demarcation (Popper, 2000b, p. 49). Therefore, Feyerabend's denial of the uniformity of scientific procedure, and his assertion that scientists use whatever methodology is suitable to the problem at hand, not limited to any particular procedure, is also a rejection of the principle of falsification as a criterion of demarcation between science and non-science. Falsification is not uniformly present in scientific procedure. Science does not need to proceed in the manner of seeking falsification.

By my interpretation, Feyerabend does not totally reject the principle of falsification. He accepts that the falsification approach can contribute to scientific development. Rather than formulating hypotheses in line with currently accepted theory, he recommends formulating hypotheses that differ from existing theory. Not only does he recommend a different approach to formulating hypotheses, but he goes further to recommend that new methodologies should also be formulated for inquiring into scientific problems. In other words, he argued that we should think out of the box of traditional practice:

> We must invent a new conceptual system that suspends, or clashes with, the most carefully established observational results, confounds the most plausible theoretical principles, and introduces perceptions that cannot form part of the existing perceptual world. (Feyerabend, 2001, pp. 22-23)

I take it that this call for new approaches to study is an attempt to falsify the principle of falsification as Popper formulated it. Popper suggests that the ultimate goal of scientific inquiry is the progress of knowledge and that in order to achieve progress, we should try to learn from mistakes and that scientists should approach the issue by attempting to falsify current theory (Popper, 1985, p. 179). Falsification is then utilized as the fundamental or standard approach that scientists apply in their research (Popper, 2000b, p. 49). Feyerabend suggests that there is no fundamental manner in which scientists approach research (Feyerabend, 2001, p. 2). This means that even the principle of falsification is not a fundamental method for science. The principle of falsification, in other words, is falsified.

In *Against Method*, Feyerabend writes that his interests are not in the growth of knowledge, but are rather humanitarian. He believes that all development throughout human history has been for the purpose of survival, not strictly for intellectual development as such (Feyerabend, 2001, p. 3). However, even though Feyerabend observes development from a humanitarian perspective, his orientation is not far from that of the principle of falsification.

Even if we assume Feyerabend's position that "development" is human-centered and thus belongs to humanitarian reason, the term "development" in any area surely includes replacing the old with the new. It is indeed evident that in any development, a new idea must be successful in defeating an existing idea. In other words, the old is overturned, or falsified, by the new. As long as there is competition between an old notion and a new notion and it is possible that the new notion conquers or forces alterations in the old notion, we are in the realm of falsification. To adopt the new is to refute the old. The growth of knowledge does not differ from Popper's notion of "proceeding from old problems to new problems," (Popper, 1979, p. 258).

4.5 Larry Laudan

Laudan proposes the concept of problem-solving as the core of scientific inquiry. He goes beyond those philosophers who aim to distinguish science from non-science by methodological criteria. Laudan is similar to Feyerabend, and I presume that his position is an extension of Feyerabend's position that there is no standard methodology of scientific research, but that any suitable means that leads to the acquisition scientific knowledge can be counted as scientific. Laudan similarly does not limit science to any particular standard method. In fact he does not pay a great deal of attention to methodology, but rather makes problem-solving the focal point of his philosophy of science:

> Science has as wide as variety of aims as individual scientists have a multitude of motivation: science aims to explain and control the natural world; scientists seek (among other thinks) truth, influence, social utility, and prestige. Each of these goals could be (and has been) used to provide a framework within which one might try to explain the development and natural of science. My approach, however, contends that a view of science as a problem-solving system holds out more hope of capturing what is most characteristic about science than any alternative framework has. (Laudan, 1978, p. 12)

While there are many different opinions on the aim of scientific inquiry, for example positivism insists that science has to proceed with attempts at verification, and Popperians argue that falsification is the means of scientific progress, Laudan proposes that success in problem-solving is superior to and overarches those other aims of science. Laudan characterizes his own philosophy as a "problem-oriented theory of science," (Laudan, 1978, p. 12). He argues that the aim of science is the resolution of problems and this makes his concept different from those of other philosophers of science in relation to the evolution of science. A scientific theory is useful only if it provides an answer to at least one scientific problem. Hence, it is the task of scientists to do research in response to specific problems within science, endeavoring to discover resolutions to those problems. He emphasizes the importance of the ability to resolve the problems of a particular theory,

> The first and essential acid test for any theory is whether it provides acceptable answers to interesting questions: whether, in other words, it provides satisfactory solutions to important problems. (Laudan, 1978, p. 13)

Laudan places the problem-oriented approach in opposition to Popperian falsification as the driver of growth in science. Even though Laudan seems unconcerned with the demarcation problem, focusing on the issue of solving the problems, it could be inferred from his argument that Popper's insistence on falsifiability as intrinsic to science is mistaken and therefore does not demarcate science from non-science. Laudan argues against the principle of falsification, suggesting that it should not be considered falsifying when we experience anomalous evidence or counter-examples to a theory. He argues that an anomaly does not falsify the theory, but rather puts into question the problem-solving ability of the theory. The theory has yet to be falsified, but clearly, the anomaly presents a problem that the theory fails to solve. He elaborates:

> When we say that '*a*' is an anomaly for a theory T_1, we are not saying that '*a*' falsified T_1…; rather, we are saying that '*a*' is the sort of problem which a theory such as T_1 ought to be able to solve (albeit in conjunction with other theories), but which it has failed as yet to solve. That, of course, does not prove that T_1 is false; but it does clearly raise doubts about the problem-solving effectiveness of T_1. (Laudan, 1978, p. 43)

It appears to me that his argument against the principle of falsification may betray a belief that in attempting to falsify a theory we have to "abandon" it. He argues that an anomaly is not sufficient to force abandonment of the theory. He suggests that the effort should be to minimize the anomaly in the theory rather than to abandon the theory (Laudan, 1978, p. 44). In response to this position, I would argue that falsifying a theory does not entail entirely eradicating or abandoning it. Rather, when we find an anomaly and it entails, at least, progress in the theory, then existing theory has been replaced with a newer version of the theory. For Popper, science progresses through falsification. I do not believe that he meant by that entire rejection of the theory, but rather that adjustment to the theory can be count as falsification and that such adjustments constitute scientific progress (Popper, 2000b, p. 72).

Laudan classifies empirical problems into three categories. The first category consists in unresolved problems, those problems to which existing knowledge and theory give no satisfactory solution. This category draws the line for the future of scientific discovery. The second category consists in resolved problems, problems that are adequately addressed by current theory. The last category consists in anomalous problems, problems that a particular theory cannot adequately resolve, but that may be resolvable by a rival theory. This last category is constituted by anomalies for existing theory that require other concepts for resolution. Within this system of classification, unresolved problems and anomalous problems are essential to the growth of scientific knowledge. Whenever scientists resolve an unsolved or an anomalous problem, or, in other words, succeed in transforming one of these problems into a resolved problem, science has advanced (Laudan, 1978, pp. 17-18).

Though Laudan's "problem-oriented theory of science" seems to differ from the models of other philosophers of science, including Popper, I would insist that this concept is not really distinct from Popper's model in which science grows through falsification. Once a scientist notices a "problem" with the facts, in Laudan's model, it is then his task to attempt to "resolve" the problem by creating a new theory or improving the existing theory so as to provide a resolution. Noticing the problem, I argue, is the same as observing an anomaly or counter-example to existing knowledge. The "problem", "anomaly", and "counter-example" are the same in providing a challenge to the current theory or knowledge. That is the initial step of scientific inquiry in Popper's falsification model.

In Laudan's model, the attempt to resolve a problem, if the problem is formulated logically and appropriately (if the problem were not formulated rationally, it would be able to contribute nothing to science), then (1) the existing theory may be improved and extended in application and capability so as to resolve the problem, or (2) it leads to radical theoretical change in which prior theory is entirely replaced. Both of these possibilities lead to change in the existing theory in a certain way, at least to minor modification making the theory better in resolving a class of problems. In other words, the existing theory has been refuted and replaced by an improved version or by the new theory

This model of the growth knowledge is not so very distant from Popper's model of scientific discovery through falsification; as Popper writes, "the growth of knowledge proceeds from old problems to new problems," (Popper, 1979, p. 258). Therefore, I argue that falsifiability as an intrinsic characteristic, or as the nature, of science has survived yet another effort at falsification, and that through falsification science achieves its objective of growing scientific knowledge, contributing to progress in science.

4.6 The Problem of Existential and Probability Statements

I noted in Chapter 3 that Popper classifies existential statements as unfalsifiable, or metaphysical (Popper, 2000b, p. 70). Gillies also notes that pure "existential statements" and "probability statements" are problems for employing the principle of falsifiability as the criterion of demarcation. Existential statements are statements that must verified by pointing to the existence of something. This kind of statement cannot be falsified because there is nothing to falsify, it is open only to proof of existence. Gillies gives as example the statement: "There is (or there exists) a white raven." This statement is verifiable but not falsifiable. There is a way to verify it, observing a white raven. But the statement cannot be falsified, because there is an uncountable number of ravens. Falsifying it would require observing all ravens in the world, which is impossible. And the statement is certainly not metaphysical. Therefore falsifiability as demarcation does not apply to existential statements. (Gillies, 1993, p. 205-210)

However, eventually, Gillies accepted Popper's response to this critique. The difficulty of existential statements for Popperian falsification is that by that criterion the statements are not scientific because of unfalsifiability, but rather metaphysical. (Gillies, 1993, pp. 205-210)

Maxwell challenges the principle of falsification as the criterion of demarcation, insisting that it is not, after all, necessary for scientific theories to be falsifiable (1974, pp. 293-301). He gives examples of universal and existential statements that seem to unfalsifiable, including, "Every solid has a melting point" or "For every solid, at a given external pressure, there is a temperature above which it becomes liquid (or gaseous)," (Maxwell, 1974, p. 295). These statements are obviously of scientific not metaphysical interest; yet they are unfalsifiable. However, Maxwell acknowledges that if we add detail to the statements, they would become falsifiable, for example, "For every pure solid substance, at a given external pressure there is exactly one melting point," (Maxwell, 1974, p. 295). Therefore, it would seem that such statements would have the characteristic of falsifiability depending on the how they are synthesized.

However, Popper suggests that it is possible to change the status of existential statements from metaphysical to scientific, if the existential statement is a part of a larger system, that could possibly make it falsifiable:

> But if taken in context with other statements, an existential statement may in some cases add to the empirical content of the whole context: it may enrich the theory to which it belongs, and may add to its degree of falsifiability or testability. In this case, the theoretical system including the existential statement in question is to be described as scientific rather than metaphysical. (Popper, 2000b, p. 70)

Another class of statements that poses problems for the principle of falsification consists in probability statements. Probability statements are a difficulty in that they cannot be falsified. For example; given the unbounded scope of occurrences, the statement "for every toss with a penny resulting in I, there is an immediate successor resulting in O", especially in the scope of "unbounded" system of observation, cannot be falsified (Popper, 2000b, p. 193). For Popper, the status of probability statements is between that of existential statements and universal statements (Popper, 2000b, pp. 192-196), and scientists can use probability statements in their studies "as" empirical statements. (Popper, 2000b, p. 204)

Gillies suggests that the probability statement difficulty can be resolved in that probability statements can be falsified through statistical methods. Although we cannot definitely falsify such statements, the statistical method opens up room to reject them (1993, p. 208). In statistical testing, criteria are defined for accepting or rejecting propositions based on data patterns, for example a 95 percent confidence interval. If the observed data fall within the defined bounds, we simply accept it as true. On the other hand, if the observed data fall outside the defined bounds, into the other 5 percent, the statement would be falsified.

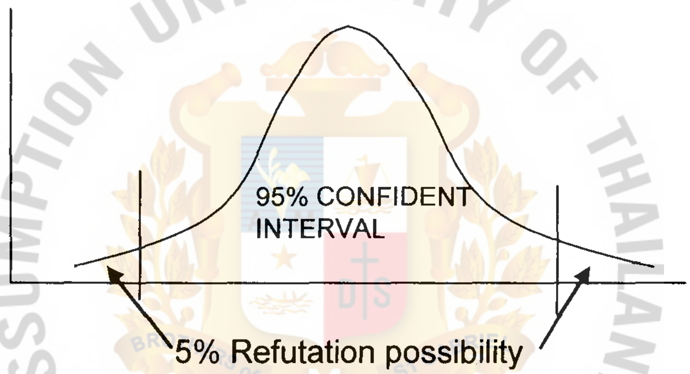


Figure 4.3: Statistical Methodology for Accepting or Rejecting a Hypothesis

Chapter 5

Critical Analysis of the Principle of Falsification

5.1 Fallibilism and Scientific Knowledge

No matter how much discussion there may be about the growth model of science and the demarcation problem, I argue that the correctness of Popper's argument that fallibility is an intrinsic attribute of scientific knowledge (Popper, 2000b, pp. 40-42) cannot be disputed. Anything that we believe, no matter how excellent the reasons for that belief, may turn out to be wrong (Mortan, 2004, p. 75). Gellner criticizes the falsification principle in that it exposes scientific knowledge to the greatest danger, leaving it no tools or methodologies to defend itself from falsification. He writes that with the falsification principle, science would be like a warrior with no army, strategy, or tactics in the face of the enemy, leaving no room for achievement (Gellner, 1979, pp. 171-172). The metaphor greatly exaggerates the situation, and such critiques are based on an improper attitude toward falsification. To stay with the warrior metaphor, Popper's concept of falsification would rather suggest that no matter how powerful, fully furnished and well prepared a warrior is, defeat always remains possible; there are no invincible warriors. Thus in science, no matter how well-formed the theory, no matter how well supported it is by the evidence, no matter how coherent it may be with the accepted body of scientific knowledge, it always remains in principle possible that the theory will be found to be false or inadequate.

Scientific knowledge is never invincible. Existing knowledge, or what is accepted as knowledge today, may be shown to be untrue tomorrow. There are many examples of opinions widely accepted as true in ancient times, that were later falsified by new discoveries. It is not that the ancients were less intelligent than moderns, but that scientific knowledge and technology had not yet advanced far enough to allow them to observe the data that would falsify their beliefs.

The development of technology, especially tools of observation, has been crucial to the falsification process and to ushering in scientific revolutions. An obvious example is that of the Copernican Revolution. Copernicus is widely accepted as the first to propose a heliocentric rather than geocentric universe. This proposal constitutes an attempt to falsify the geocentric theory. However, his proposal was not widely accepted until Galileo used the newly invented telescope to observe the stars and planets. With the telescope, Galileo was able to observe heavenly bodies invisible to the unaided eye (Fetzer, 1993, p. 4). The telescope is a magnifying tool and was able to provide sufficient evidence to falsify the belief that the earth is at the center of the universe, ushering in a revolution in human knowledge and making room for Copernicus' better heliocentric theory. On a minute scale, the microscope allows us to discover that there are very tiny living things, such as bacteria and viruses, which are also invisible to the naked eye.

Nevertheless, there remains the critique that, on the theoretical level, it may not be justifiably claimed that scientific knowledge is falsifiable. For example, comparing Newtonian physics, relativity, and quantum theory, Brown argues that it is difficult to judge which is the more acceptable:

> It would be hard to find a clearer indication of the fact that we have much greater confidence in the truth of relativity and quantum theory than we do in Newtonian mechanics, and that we only use the latter when it provides a convenient approximation. (Brown, 1990, p. 200)

It seems that the relativity and quantum theories have developed away from Newtonian physics. Nonetheless, in practical life Newtonian physics has not been eradicated from the scientific community. Newtonian physics is still useful in the scientific community in a restricted range of cases. Brown suggests conditions under which Newtonian techniques remain applicable:

> These cases must meet two conditions: first, we must be dealing with a problem in which it is known that the results of the Newtonian calculation are sufficiently close to the results of the relativistic or quantum theoretical calculation that it makes no difference which we use, given our present purposes. Second, the Newtonian calculation must be easier to carry out than the relativistic or quantum theoretical calculation, else there would be no point to the approximation. (Brown, 1990, p. 200)

In practical life, a new theory may not radically falsify the old theory. Though the new theory may have more explanation power than the previous theory, the old theory may remain applicable in certain situations.

The inferiority of the previous theory may be compensated by other parameters such as simplicity. For example, Einstein's theory is more acceptable than Newton's for calculating the motion of Mercury. Predictions of that motion utilizing Newton's theory deviates from observed reality, whereas predictions from Einstein's theory do not. However, this consequence has not eradicated Newtonian theory from the scientific community and it is still widely used for practical purposes. Calculations using Newtonian theory deviate very little from observed reality, especially in normal situations, and the theory is simpler and the calculations easier than with Einstein's theory. (Hawking, 1988, p. 12)

Therefore, as in the above example, the falsification of a theory may not be significant in practical life. The scientific community may not need to select the more advanced theory in conducting research. Scientists could rather select the more appropriate theory based on the situation. Therefore, the previous theory may not need to be eliminated, even though the new theory has more explanatory power.

Although Newtonian mechanics is still used by scientists today, it is widely admitted to be inferior to Einstein's relativity and Quantum mechanics in terms of its correctness. People apply Newtonian theory in calculations because of its simplicity and because it produces acceptable results. However, it cannot be denied that both relativity theory and quantum mechanics have falsified Newtonian mechanics. As Okasha states, "Confidence in the Newtonian picture was shattered in the early years of the 20th century, thanks to two revolutionary new developments in physics: relativity theory and quantum mechanics" (Okasha, 2002, p. 8).

I think that the fact that people still use Newtonian does not mean that the theory cannot be falsified. It also has the attribute of falsifiability and it is possible that in the future scientists will find a way to falsify it.

Scientists create many theories in their attempts to explain the universe. Each theory has a boundary of observation within which it is applicable. Therefore, it is possible that we cannot judge which theory is truer than the others, or which is true and which is false, since each theory may explain reality in a difference context. Hawking gives an example of this situation:

> Today scientists describe the universe in terms of two basic partial theories – the general theory of relativity and quantum mechanics. They are the great

> intellectual achievements of the first half of this century. The general theory of relativity describes the force of gravity and the large-scale structure of the universe, that is the structure on scales from only a few miles to as large as a million million million million (1 with twenty-four zeros after it) miles, the size of the observable universe. Quantum mechanics, on the other hand, deals with phenomena on extremely small scales, such as a millionth of a millionth of an inch. Unfortunately, however, these two theories are known to be inconsistent with each other – they cannot both be correct. (Hawking, 1988, p. 13)

However, this does not mean that these theories are unfalsifiable. It rather manifests that they have limitations. This example does not contradict Popper's concept of falsifiability as a characteristic of science. The indecisiveness in judging which is better is because they are both imperfect theories. It is just that scientists have yet to find a theory with the explanatory power to cover the entire scope of interest, able to explain both the minute and the very large. When we find a theory that overcomes the limitations of explanation of these theories, they will have both been falsified, and that will be an important step in the progress of scientific knowledge.

Knowledge of the expansion of the universe leads to the notion of its origin: the Big Bang. At the Big Bang the amount of space between galaxies would be zero, which means that the density of the universe and the curvature of space-time would be infinite. At this point, no mathematical model or classical scientific theory could give an explanation. This point is called a "singularity" (Hawking, 1988, p. 52).

This suggests that every theory has limitations. Limitations on a theory's explanatory power depend on context. If the context changes it is possible that the theory will not be able to answer to the situation. If we find a better theory that extends the scope of the theory's explanatory power and reduces limitations on applicability, we can say that the theory has progressed. Scientists aim to find a super theory that would give answers to everything in the universe and also be applicable to the singularity. However, we have yet to find a theory to answer to the singularity.

Quantum mechanics suggests that it may not be necessary to develop new scientific theories to explain the singularity, because in reality there may be no singularity at the beginning point of the universe (Hawking, 1988, p. 148). But this may not yet be the conclusion. There are many theories, from the classical theory to quantum theory, trying to understand the beginning of the universe, the pathways through which the current situation developed and possibilities of the future. For example, (1) a stationary universe in finite but unbounded time—no beginning and no end, (2) the universe started at a finite time, at the singularity, and (3), according to the quantum theory, the universe started at a finite space-time "moment" which was not a singularity (Hawking, 1988, p. 151). My point here is to indicate the difficulty or impossibility of determining which theory is true, as it seems that it is not possible to have any direct experience of the beginning of the universe. Hence, how can we judge what theory can give us the truth about it? All proposed theories are based on inferences from current observations. And all these theories can be challenged and falsified by new information and the imagination and rationality of scientists in synthesizing new theories.

Therefore I support Popper's notion in that all scientific knowledge is falsifiable. Even what cannot be proven or falsified today, but through the advancement of scientific knowledge and of technology, it may possibly be proven or falsified in the future. Scientific knowledge is not certain knowledge. As Hawking writes in his famous work, *A Brief History of Time*, showing his notion on uncertain of scientific knowledge that:

> Any physical theory is always provisional, in the sense that it is a hypothesis: you can never prove it. No matter how many times the results of experiments agree with some theory, you can never be sure that the next time the result will not contradict the theory. (Hawking, 1988, p. 11)

Barbour supports the concept of scientific uncertainty: "In sum, science does not lead to certainty. Its conclusions are always incomplete, tentative, and subject to revision. Theories change in time, and we should expect current theories to be modified or overthrown, as previous ones have been," (Barbour, 1997, p. 110).

Therefore, it may be concluded that in the realm of science, there is no absolute knowledge. In other words, all scientific knowledge is open to falsification. Falsifiability is essential to the progress of science. If all scientific knowledge were invincible, there could be no new knowledge, scientific investigation could only seek to corroborate existing theory and what we know today would be exactly the same as what was known by the ancients. Falsifiability, on the other hand, opens the opportunity for scientists to overthrow accepted knowledge and to replace it with new knowledge.

5.2 Concepts of Scientific Progress

All the major philosophers of science discussed in chapter 4, Popper, Kuhn, Lakatos, Quine, Feyerabend, and Laudan are equally interested in the growth of scientific knowledge. Each takes his own position on how the progress of knowledge occurs, differing from each other in important ways. Popper (1979, p. 258) believes that science progresses through the process of falsification. Kuhn (1970, pp. 10-42) argues that the growth of scientific knowledge occurs through paradigm shifts. For Lakatos (1995, pp. 100-114), science can grow through extending the explanatory power of research programs. Quine (1992, pp. 12-16) suggests that progress of science consists in the readjustment or revision of theories. Feyerabend (2001, pp. 1-11) opposes the idea that any single method accounts for the growth of science. He argues rather that human beings use no specific method of development and recommends utilizing whatever method is appropriate to the specific issue at hand. There is no standard method applicable to all problems; once we have found the better method for the particular problem, science will progress. Laudan (1978, pp. 12-44) takes a problem-oriented approach to the scientific game. Science progresses as current problems are solved.

Even though the models of the growth of science of major philosophers of science are different in detail, there are common characteristics among them. These models are similar in the initiating conditions specified for growth. It has to be accepted that these initiating conditions are different, but one common feature is that growth is initiated when current theory or existing knowledge has trouble with, or does not satisfactorily explain phenomena, for example, when faced with a counter-example contradicting existing theory. Scientists then search for better knowledge capable of resolving the problem or explaining the counter-example.

Once the initiating conditions have been satisfied, what follows is competition between the old and the new, challenging, theory. If the new theory defeats the old theory, science has progressed.

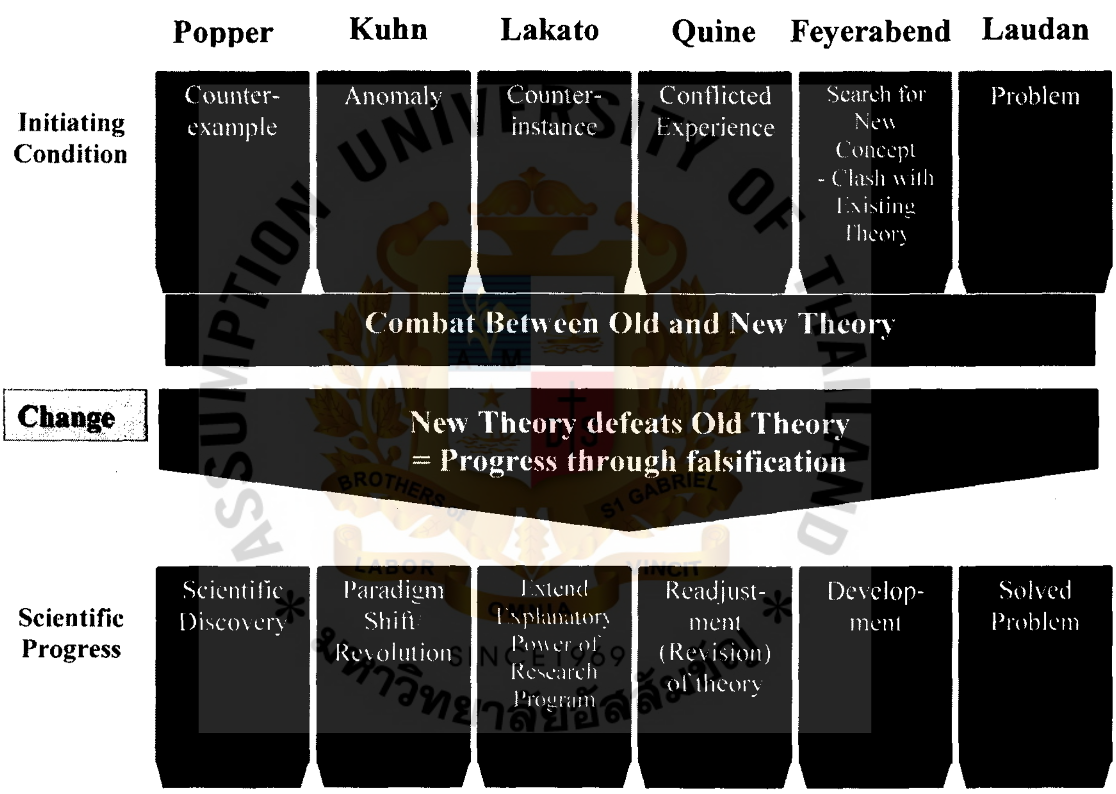


Figure 5.1: Concepts of Progress in Science

The principle of falsification as articulated by Popper has been critiqued by these philosophers of science, but it would seem that their arguments do not entirely refute the concept that science grows through falsification to the point that new knowledge conquers existing theory.

Tracing the history of science, we find that scientific knowledge advanced though a process of falsification as new knowledge defeated previous knowledge. One important example of this is Galileo's mechanical experiment falsifying Aristotle's theory of motion (Okasha, 2002, p. 4-5). Aristotle thought that a heavier body would fall faster than a lighter one. That theory was falsified by Galileo when he did an experiment and found that mass does not make any difference in the speed of a fall. Heavier and lighter balls fall at the same rate of acceleration (Hawking, 1988, p. 17-18). Through Newton's theory, we gained more understanding of the situation. Hawking says:

> One can now see why all bodies fall at the same rate: a body of twice the weight will have twice the force of gravity pulling it down, but it will also have twice the mass. According to Newton's second law, these two effects will exactly cancel each other, so the acceleration will be the same in all cases. (Hawking, 1988, p. 19)

Another theory of Aristotle that was falsified was that the natural state of any body is to remain stationary, and that a body would move only when it was driven by force or impulse. That theory was falsified by Newton's laws of motion. For Newton, there is no real stationary state. A body can only be said to be stationary relative to the motion of some other body. According to the new theory, a body's velocity will change when force is applied to it. As long as no force is applied, a stationary body remains stationary and a moving body continues its movement at the same velocity (Hawking, 1988, p. 19).

Another example of the progress of scientific knowledge through falsification has to do with scientific inquiry into the fundamental constituents of matter. In ancient Greece, Democritus taught that the fundamental constituent was an indivisible particle that he called the “atom”. The existence of atoms was confirmed by John Dalton in 1803 and by Einstein in 1905. Dalton proved the existence of atoms by pointing out that molecules of chemical compounds are combinations of atoms. Einstein proved their existence by his discovery of the irregular motion of small particles in a liquid due to atoms colliding with the particles (Hawking, 1988, p. 69-70).

The belief that the atom is the fundamental particle, however, was falsified when J. J. Thomson proved the existence of the electron as a constituent of atoms in 1897 (Hawking, 1988, p. 70; S. Strickland & E. Strickland, 2006, p. 58). The mass of an electron is less than one part per thousand of an atom. Ernest Rutherford showed that the atom is a combination of positively charged particles, protons, and negatively charged particles, electrons. Protons are in the core, or nucleus, of the atom and surrounding by electrons. Rutherford thought that what he had found were the fundamental particles, but that belief was later falsified by James Chadwick who discovered the existence of neutrons within the nucleus, similar to protons but with no electrical charge (Hawking, 1988, p. 70).

After Chadwick’s discovery in 1932, people believed that protons and neutrons are fundamental, indivisible particles. However, about twenty years later Merray Gell-Mann shot protons at other high speed protons or electrons and discovered smaller particles that were components of protons. Those smaller particles are called “quarks” (Hawking, 1988, p. 70-71). Protons are thus divisible after all.

This example of growth of knowledge about fundamental particles, from atoms to quarks, demonstrates that scientific knowledge can grow through success in the falsification of previous ideas. This story also makes us realize that it may be impossible to guarantee that what we know today will not be falsified one day in the future.

Many other examples show that scientific knowledge can grow through the rectification of misunderstanding. People used to believe that plants take carbon from the soil. In 1804, Nicholas de Saussure falsified that belief and suggested that plants get carbon from carbon dioxide in the air (S. Strickland & E. Strickland, 2006, p. 41).

Knowledge about the structure of universe is also a good example of the growth of knowledge though falsification. It was once believed that the universe is in a static state, not contracted by gravity because of a counteracting antigravity force resulting in stasis. Alexander Friedman formulated assumptions leading to the conclusion that the universe is not static but rather expanding. Edwin Hubble then proved the theory that the universe is expanding by studying the spectra of waves coming from the universe. He found that the spectra were shifted toward the red end, meaning that the stars are moving away from us. If the spectra were shifted toward the blue end, that would mean that the stars were moving toward us, and therefore that the universe is contracting (Hawking, 1988, p. 41-44). It could then be inferred that the universe is not contracting but rather expanding. This is a good example showing that scientific knowledge can grow through the methodology of falsification. Hubble's observation's falsified the belief that the universe is at rest. That belief was then replaced by the belief that the universe is expanding.

Nonetheless, it is an interesting question whether these processes in fact lead to scientific progress. How can we be sure that all situations in which a new theory defeats an old one represent improvement? Kuhn's concept of a paradigm shift is that a new paradigm takes over the role of the prior paradigm, a scientific revolution; but it is not necessarily the case that the new is better than the old (Feyerabend, 2004, p. 261). Therefore, even if we find commonalities among these models of growth, it does not follow that the success of a new theory is always progress. The consequence is that we can hardly infer that all falsification leads to progress.

There is a question whether and how theories can conclusively be falsified, in that there are typically multiple alternative explanations for a failure. However, this does not contradict Popper's philosophy of science, because Popper thinks that it is impossible to attain truth. For Popper, the problem of induction stands in the way of the search for conclusive proof. Hence, we also cannot have conclusive falsification (Stiver, 1996, p. 47). What we today think is wrong may turn out tomorrow to be valid if we find evidence to support it.

Nonetheless, it is untenable to deny that falsification has brought at least some changes to our systems of thought. Falsification leads to changes in existing theories, notions, understandings and even beliefs to new ones, newer versions of the given body of knowledge. Worrall applies the word "change" in discussing Popper's model of the development of science. He writes, "Science and in particular the process of theory-change in science, formed the major inspiration for Karl Popper's whole philosophy. … Popper saw the development of science, through the process of change in accepted theory," (Worrall, 2004, p. 488). When new knowledge succeeds in the combat between the new and the old, without the capability of judging that event is a genuine improvement in knowledge, we can at least be sure that there have been changes of knowledge, whether major or minor. Hence, even if it is problematic to say that falsification contributes to progress, it is certainly the case that it brings change. In this way, we can resolve the concerns of those philosophers who, like Kuhn, argue that we cannot conclude that paradigm shifts occur because the new paradigm is better than the displaced one (Feyerabend, 2004, p. 261), but rather that it prevails because of greater acceptance in the scientific community, because the community has changed its paradigm to the new one (Kuhn, 1970, pp. 158-159).

Kneale (2004, p. 448) advocates the notion of the instability of scientific knowledge, by which he means the infinite process of searching for scientific knowledge:

> Within the last few years a number of philosophers of science have suggested that it would be a sad ending of scientific endeavour if mankind ever came to permanent acceptance of a single theoretical framework. In their view intellectual life is at its best when each hypothesis is succeeded after a while by a better, so that science never reaches stability. (Kneale, 2004, p. 437)

The instability of scientific knowledge implies that science is open to change, and, in particular, to progress.

5.3 Critiques of the Principle of Falsification as Criterion of Demarcation

5.3.1 Falsification of Metaphysics and Religious Beliefs

In the world of practical affairs, many people, thinking superficially, seem to believe that the more scientific knowledge advances, the less room there is for metaphysical and theological knowledge. Scientific knowledge, including technological development, can give answers to many questions that our ancestors could not answer. We use the telescope to observe the stars and planets in space extremely far from our world, and scientists can now calculate the directions and movements of the planets. Scientists can prove that there are such entities such as electrons, protons, and neutrons that are smaller than the atom which once was believed to be the smallest entity in the world, as proposed by the ancient philosopher, Democritus. But to claim that only scientific knowledge is meaningful and that metaphysics is meaningless is too extreme and one sided; our lives do not have only one side.

One motivation behind critiques of the principle of verification, in my view, is the extremity of judging propositions as meaningful or as meaningless in such a way as to define all but scientific knowledge as meaningless. This concept naturally generates controversy as it looks down on other sorts of knowledge. If the positivist principle is accepted, then what metaphysicians and religious persons have learned is meaningless.

I admire Popper in that, even though he is widely recognized as a major philosopher of science, he does not look down other kinds of knowledge. He argues against the principle of verification as the criterion of demarcation in part because it treats other than scientific knowledge as meaningless. He writes, "The repeated attempts made by Rudolf Carnap to show that the demarcation between science and metaphysics coincides with that between sense and nonsense have failed". He adds that this positivist's line of demarcation is "inappropriate" because, "metaphysics need not to be meaningless even though it is not science," (Popper, 2000a, p. 253).

He further adds that, contrary to the positivists, he respects metaphysics by bearing in mind that metaphysics has a vital role in scientific discovery:

> I do not even go so far as to assert that metaphysics has no value for empirical science. … I am inclined to think that scientific discovery is impossible without faith in ideas which are of a purely speculative kind, and sometimes even quite hazy; a faith which is completely unwarranted from the point of view of science, and which, to that extent, is 'metaphysical'. (Popper, 2000b, p. 38)

In order to resolve the difficulties of the principle of verification, Popper wisely proposed the principle of falsification in its place. These two principles seem to be situated at opposite sides of a balance position.

Although the principle of falsification has solved the problem of induction that plagues the workability of the principle of verification in making a distinction between science and non-science, there are critics who point to weaknesses in applying the principle of falsification to delimit science from non-science, especially from metaphysics.

There are examples of Popper's criterion failing to distinguish science from non-science. An obvious example is Darwinian evolution, which is certainly science, yet cannot be falsified. Psychoanalytic theory poses another problem for demarcation through the principle of falsification (Grunbaum, 2004, p. 392) in that using the falsifiability principle as the criterion of demarcation, psychoanalysis is not science. Popper's line of demarcation excludes this sort of knowledge, because psychoanalysis tries to explain all behavior, making psychoanalytical theory always survive from falsification. Thus, there are no cases that would conflict with psychoanalytic theory (Popper, 1999a, p. 17).

I believe that metaphysics consists in knowledge about the world, as does science. The difference is that scientific theories can be proved by empirical evidence, while metaphysical theories cannot. This is why Popper treats metaphysics differently from science, because metaphysical knowledge cannot be refuted by experience (Popper, 2000b, p. 41). Nonetheless, I would add that the principle of falsification may not succeed in excluding from science such metaphysical statements as, "lightning is the deed of a goddess." In ancient times, this belief, according to the falsifiability criterion, would have counted as metaphysical because there was no means of falsification. However, there have been many cases in which people, including scientists, have tried to determine the truth or falsity of such metaphysical beliefs, and it is possible that one day scientists will find means of testing them, methods of falsification. If that were to happen, then what would be classed a metaphysical proposition today by Popper's line of demarcation, would come to be classed as a scientific proposition. Throughout the history science, many previously metaphysical statements, that is, statements that we did not know how to falsify, later became falsifiable. The above example of belief that lightning is the deed of a goddess has now been falsified by development of scientific knowledge, relegating it to the status a folk tale. Lightning is explained through the discipline of science. Hence, a metaphysical proposition has been falsified, hence is falsifiable, even though it is in a different period. This may lead us to suspect that, finally, there is no distinction between science and metaphysics, at least if we accept the principle of falsification as making that distinction.

Actually, Popper does not really think that metaphysical theories or even myths are necessarily unfalsifiable. It is only that they cannot be "empirically" tested by present methodology, or that we cannot exemplify the empirical evidence to falsify it. He writes:

> At the same time I realized that such myths may be developed, and become testable, that historically speaking all – or very nearly all – scientific theories originate from myths, and that a myth may contain important anticipations of scientific theories. Examples are Empedocles' theory of evolution by trial and error, or Parmenides' myth of the unchanging block universe in which nothing ever happens and which, if we add another dimension, between Einstein's block universe (in which, too, nothing ever happens, since everything is, four-dimensionally speaking, determined and laid down from the beginning). I thus felt that if a theory is found to be non-scientific, or 'metaphysical' (as we might say), it is not thereby found to be unimportant, or insignificant, or 'meaningless', or 'nonsensical'. But it cannot claim to be backed by empirical evidence in the scientific sense – although it may easily be, in some genetic sense, the 'result of observation'. (Popper, 2000a, p. 38)

Popper admits that his demarcation does not in the rigorous sense delimit science from metaphysics, "Any demarcation in my sense must be rough. … For the transition between metaphysics and science is not a sharp one: what was a metaphysical idea yesterday can become a testable scientific theory tomorrow; and this happens frequently," (Popper, 1974, p. 981).

This discloses his ideas on the character of metaphysical theory, that metaphysical theories have a pre-scientific character and may be developed into scientific theories in the future when we find substantial empirical evidence. This, for me, suggests some contradictions in his philosophy, as he says that only science is falsifiable while saying above that metaphysical theory can also become science. But that means that metaphysical theories are also falsifiable. Therefore, we must ask whether falsifiability adequately demarcates science from non-scientific disciplines such as metaphysics.

Lakatos mentions the possibility of falsifying metaphysical theories, of replacing of an old metaphysical theory with a new metaphysical theory:

> We eliminate it if it produces a degenerating shift in the long run and there is a better, rival, metaphysics to replace it. The methodology of a research programme with a 'metaphysical' core does not differ from the methodology of one with a 'refutable' core except perhaps for the logical level of the inconsistencies which are the driving force of the programme. (Lakatos, 1995, pp. 126-127)

Lakatos gives another example of a metaphysical statement changing over to a scientific statement, "For instance, instead of formulating Cartesian metaphysics as an 'all-some' statement ["in all natural process there is a clockwork mechanism regulate by animating principle," (Lakatos, 1995, p. 126)], we can formulate it as an 'all-statement: 'all natural processes are clockworks," (Lakatos, 1995, p. 127). He emphasized that, at different times, it is possible to change the form of a statement in accord with the level knowledge at a particular moment "Thus the rational choice of logical form of a theory depends on the state of our knowledge; for instance, a metaphysical 'all-some' statement of today may become, with the change in the level of observational theories, a scientific 'all-statement' tomorrow," (Lakatos, 1995, p. 127). Lakatos disagrees with Popper's position that metaphysics "influences" scientific knowledge. For him, metaphysics is rather "an integral part of science"

(Lakatos, 1974, p. 265). Therefore, for Lakatos, we should not distinguish metaphysics from science.

Recall Popper's classification of existential statements as metaphysical on the basis that no means could be found to falsify them (Popper, 2000b, p. 69). Kneale criticizes this position:

> To call them all metaphysical is very curious, because most of them have nothing at all to do with metaphysics as understood by Aristotle or any other philosopher until the positivists of this century began to use 'metaphysical' in a grossly extended sense for purposes of abuse (Kneale, 1974, p. 206).

I argue that the problem with attempts to falsify existential statements is only a matter of the logical form of the statement. For example, if we are interested in a metaphysical entity like a ghost, we may synthesize the statement: "Ghosts haunt those who are afraid of them." The statement is now open to falsification attempts by searching for evidence that those who are not afraid of ghosts may be haunted. Therefore, even though Popper's demarcation criterion encounters difficulty with the existential statement, we can deal with the metaphysical entity by setting the sentence in another form that makes it science.

In religious studies, there are also issues that challenge dogmas; religious belief can also be challenged, and changed. Wisdom mentions cases in which beliefs in religious dogmas have been challenged. For example, challenges to and changes in the way that people think about gods. He gives an example in which two people may analyze and conclude differently about the same phenomenon (Wisdom, 1983, pp. 338-351). Flew adds his discussion of challenges to belief in God. The evil things in the empirical world can shake people's ideas of God by creating doubts about God's existence, omnipotence or benevolence (Flew, 1968, pp. 48-49). Though it may seem impossible to get full consensus on changes in response to challenges to religious beliefs, we can at least agree that religious belief is also open to challenge.

Barbour applies Kuhn's concept of paradigm, which has to do with scientific knowledge, to religious studies. Religious experiences are influenced by religious belief. Belief here corresponds to the normal paradigm. In the scientific community, he notes that though the normal paradigm is resistant to falsification, it nevertheless can be falsified under the cumulative weight of anomalies. Similarly, religious paradigms are also resistant to falsification, but capable of falsification and abandonment (Barbour, 1997, p. 128).

Barbour notes the possibility of change in theologies. He gives as examples of theological revolutions, "the Protestant Reformation, or the emergence of Mahayana from Theravada Buddhism, do involve extensive and fundamental changes," (Barbour, 1997, p. 132). This may imply that even in religion, change is possible. People in a community may reject or change their religious beliefs to new ones. Therefore, we must reject as invalid Popper's position that the principle of falsification holds only for science.

5.3.2 Applying Scientific Methodology to Political Issues

Popper applies scientific methodology to politics, arguing against the closed societies of totalitarianism and of historicism, for which society is believed to have an immutable destiny. Popper's concept of an open society includes a dynamism of political concepts, a society that is open to, and has the possibility of, change. Childs explicates Popper's political thought as follows:

> Popper sees totalitarianism of all stripes as essentially *tribal*, as a "closed society", a rebellion against the "strain of civilization". He assaults it by using his philosophy of science (which greatly emphasizes "falsification", i.e. the refutation of statements and theories) to criticize the doctrines of those whom Popper takes to be behind modern totalitarianism, namely Plato, Aristotle, Hegel and Marx. In *The Open Society*, he seeks to "examine the application of the critical and rational methods of science to the problems of the Open Society." [He] analyzes the principles of democratic social reconstruction, the principles of... "piecemeal social engineering" in opposition to "Utopian social engineering". (Childs, 1976, para. 4)

Winch asserts that Popper's scientific methodology is applicable to social agendas. Social systems can evolve through a process of "trial and error", changing and replacing or improving to a better system. He writes:

> Just as the scientist works in a context of accepted theories, so the social engineer works in a context of existing traditions and institutions; and both proceed by 'making little adjustments and changes', using the method of trial and error (Winch, 1974, p. 901).

He adds:

> It may be all very well to say that improvements in our understanding and in the quality of our social life must come about via methods of trial and error. (Winch, 1974, p. 903)

If the society is open, it is ready to be criticized, and I presume that that includes the ability to change, with the objective of resolving problems in the society. In order to change, there must be competition between existing notions and new notions. If the new notions are reasonable and gain greater public acceptance, the old notions will then be replaced. In other words, this process follows Popper's model of scientific discovery, successful falsification.

Social and political structures, therefore, can also be falsified. They are also open to change. Existing political concepts in a society can be challenged by new competing concepts. Whenever the newer concepts are successful in defeating and falsifying the previous ones, the society will be reformed in compliance with the new political theory. This means that even political and social beliefs can be falsified. Popper expresses his social and political philosophy in the two volumes of *The Open Society and Its Enemies*. He challenges Plato's political concepts, claiming that they represent the morality of the closed society. He rejects Plato's utopia, as he thought that Plato's totalitarianism is a collective of group or tribe selfishness (Popper, 1999b, p. 108). He rather suggests the concept of the open society, or liberal democracy.

Popper criticizes historicism. For him, the history of a society does not determine its structure and we cannot predict the future form of any society. There is no prophecy capable of telling us the ultimate political form of society. Criticizing Marx's historical prophecies he writes,

> The arguments underlying Marx's historical prophecy are invalid. ... The reason for his failure as a prophet lies entirely in the poverty of historicism as such, in the simple fact that even if we observe to-day what appears to be a

historical tendency or trend, we cannot know whether it will have the same appearance to-morrow. (Popper, 1999c, p. 193)

In addition, Popper gives an example showing that Marxist theory has been falsified. What Marx thought would occur has not occurred. Capitalism has not turned out as badly as he thought it would. Today, although capitalism is expanding very quickly, it is not doing so in conformity with Marxist theory.

> Marx's terrible picture of the economy of his time is only too true. But his law that misery must increase together with accumulation does not hold. Means of production have accumulated and the productivity of labour has increased since his day to an extent which even he would hardly have thought possible. But child labour, working hours, the agony of toil, and the precariousness of the worker's existence, have not increased; they have declined. (Popper, 1999c, p. 186)

Kuhn uses the term "revolution" to represent development in science. This explicitly reflects what he believed was a similarity between science and politics in respect of development.

> One aspect of the parallelism must already be apparent. Political revolutions are inaugurated by a growing sense, often restricted to a segment of the political community, that existing institutions have ceased adequately to meet the problems posed by an environment that they have in part created. In much the same way, scientific revolutions are inaugurated by a growing sense, again often restricted to a narrow subdivision of the scientific community that an existing paradigm has ceased to function adequately in the exploration of an

aspect of nature to which that paradigm itself had previously led the way. (Kuhn, 1970, p. 92)

Kuhn and Popper are similar in that within both their models of scientific methodology, science progresses whenever a new theory accomplishes the task of rejecting or falsifying existing knowledge. It is evident that both also apply this concept to politics. For them, both science and politics develop through competition between existing notions and new concepts, through crisis. Revolution succeeds only when new competitors have conquered the existing ones. Kuhn thinks that science and politics are also the same in the difficulty of achieving revolution. Therefore, politics and science are same in their means of progress, in that existing notions can be replaced and rejected by new ones.

It may then be inferred that even politics is falsifiable. Hence, that the principle of falsification as the criterion of demarcation between science and non-science has come further into doubt. Science and politics, here, can both be classified as falsifiable matter and the principle of falsification fails to differentiate science from politics.

Gellner notes that Popper has applied his philosophy of science, especially the concept of falsification, to social and political issues.

His [Popper's] social ethic consists essentially of the commendation of the virtue of openness, which is social equivalent of falsifiability – the holding of social principles without rigidity, in a spirit which is willing to learn, innovate, experiment and change. ... The Popperian ideal of the Open Society is visibly inspired by his account of the scientific community. He endeavors to extend to society the specific merits of science. (Gellner, 1979, p. 172)

This statement supports our notion that science and society are similar in that they are both open to change. Gellner elaborated on falsifiability as, "the holding of social principles without rigidity, a spirit which is willing to learn, innovate, experiment and change." We can infer that to falsify is to bring about "change". The above quote includes Gellner's belief that Popper applied the falsifiability characteristic of science to social topics and that means that whatever the social agenda, it can be changed, or falsified (Gellner, 1979, p. 172). These considerations certainly shake the validity of Popper's thesis that the principle of falsifiability provides the criterion of demarcation between science and non-science.

5.4 Limitations of the Principle of Falsification

I think that Popper's falsification maneuver makes essential contributions to the progress of knowledge. "Progress" or "development" is a very important target in the epistemological realm. In searching for scientific knowledge, Kneale thinks, in the same way as does Popper, that it is impossible for us to achieve the absolute truth; as he writes, "For in order to attain such certainty we should have to know everything about nature, including the fact that we knew everything about nature; and I believe that to be impossible in principle," (Kneale, 2004, p. 448). He even suggests that "the human race may be too stupid for the task," (Kneale, 2004, p. 448). He adds that revolution in science is a perpetual process (Kneale, 2004, p. 448). I support his ideas, in that the attempt to acquire scientific knowledge should be a continuous work of the scientific world.

Bronowski agrees with Popper that knowledge grows through falsification. He supports Popper's model, in which the growth of knowledge is, "promoted by clearing away the rubbish of mistaken theories or superstitions." Knowledge grows by replacing existing items of knowledge with "better or more satisfactory ones," (Bronowski, 1974, p. 623).

He admires Popper for his contributions in encouraging people to continuously challenge existing notions and bring about change and growth. He writes:

> For he insisted in his philosophy as much as in his life that there is no final sanction and authority for knowledge, even in science; that only is knowledge which is free to change and grow; and that a condition for its growth is the challenge by independent minds. (Bronowski, 1974, p. 629)

However, the search for progress or the development of knowledge should not be limited to science. Popper's model of the growth of knowledge should be extended to cover other areas. The attempt to falsify theory alerts us to the search for something different from what we dogmatically think and believe, provoking us to think out of the box. If the people of the world have none of this attitude, believing wholeheartedly in what they have known, never creating new theories or challenging current ones, knowledge of the world will never progress. Knowledge would be static. What we know today would remain exactly the same as what people in ancient times knew, and we would continue to believe that disasters such as drought, flood, storm, volcano eruptions, and even sickness and pandemics were acts of the gods. But there were, in fact, theories to confront and defeat misbelief and false opinion and to pull us to more advanced knowledge, giving us more reasonable explanations for those phenomena. This progress also brings those phenomena out of the realm of metaphysical theory and into the realm of scientific theory. Hence, the metaphysical theories concerning these phenomena have been falsified.

Therefore, through the process of falsification, metaphysical knowledge has progressed. In other words, metaphysics can also progress through falsification. If we can falsify existing metaphysical theory, either by empirical or psychological methods, we are able to change popular notions and convince the people to accept new ideas.

In some extent, Popper himself does not really refute the notion that other sorts of knowledge may progress via falsification, learning from mistakes. Moreover, he suggests that even animals can acquire knowledge through mistakes.

> I believe, to the growth of pre-scientific knowledge also – that is to say, to the general way in which men, and even animals, acquire new factual knowledge about the world. The method of learning by trial and error – of learning from our mistakes – seems to be fundamentally the same whether it is practiced by lower or by higher animals, by chimpanzees or by men of science. My interest is not merely in the theory of scientific of knowledge, but rather in the theory of knowledge in general. Yet the study of the growth of scientific knowledge is, I believe, the most fruitful way of studying the growth of knowledge in general. (Popper, 1985, p. 171)

As I have noted, it is not necessarily progressive when people throw out an existing notion and adopt a new one, but at least we can say that notions have changed. But if there were no change, progress would be impossible. This concept can also apply to metaphysical theories as they also have the possibility of change, and it is through change, not static, that progress can occur.

Therefore, old metaphysical beliefs can be replaced by new ones and there are combats between old theories and new challenging ones. None of this is different from the process of scientific progress. Both science and metaphysics can change when existing knowledge is defeated. Hence, it is not valid to claim that metaphysics has no falsifiability. Claiming that metaphysical theories are not falsifiable is claiming that metaphysical theory is unchangeable and has never developed. It is obvious that throughout human history metaphysical beliefs have never ceased changing, and continue to do so today. Metaphysics is also open to change.

The methodological attitude of pursuing the falsification of existing theory is valid for metaphysics. In other words, Popperian falsifiability is not applicable as a criterion of demarcation between science and non-science. Though he argued that metaphysics may merely be pre-science, (Popper, 2000a, p. 38), it cannot be denied that metaphysics also includes falsifiability.

Kuhn argues that astrology does not differ from physics, chemistry, and astronomy, in that all of them falsifiable by Popper's definitions. Astrology and other sorts of theories are the same in that existing theory may conceivably fail to predict or explain empirical observations. This means that all are the same in their imperfection. The consequence is that all must improve their theories over time in order to accommodate failed observations (Kuhn, 2004, pp. 240-241). Grunbaum (2004, pp. 392-398) argues that even psychoanalysis is falsifiable, as he puts it:

> The hypothesized etiologic role of repressed homosexuality leads "to the necessary conclusion that the persecutor must be of the same sex as the person persecuted". ... It is, of course, logically possible that any and every paranoiac feels persecuted only by members of the opposite sex. For this reason alone, Freud's etiology is falsifiable by a finite number of such instances in the face of Popper's own denial of such falsifiability! (Grunbaun, 2004, p. 396).

Popper is excellent in encouraging people to pursue falsification. This contributes to the development of human knowledge. It teaches people not to blindly accept all that they have been taught, and it teaches them to look for new and challenging things that would falsify or defeat old theories, bringing the development of knowledge. However, his insistence that falsifiability demarcates science from non-science denies the power of falsifiability to other sorts of knowledge which could be developed in the same manner, replacing old theories with newer ones. Putnam criticizes Popper's attempt to demarcate science from non-science as a failure to see the primacy of practice. This failure leads him to sharply demarcate science from other fields, separating theory from practice, while Putnam stresses that practice is primary (Putnam, 1974, p. 239).

Meyer complains that a problem with the search for a standard methodological approach in the philosophy of science is that it limits the applicability and power of that particular method to science, when it may be applicable and beneficial to inquiries in other fields of knowledge.

> Indeed, the most important reason to question methodological naturalism is not that it undermines the claims of religion; the best reason to question the doctrine is that it limits the prerogatives of science. Methodological naturalism

> is not so much irreligious, as irrational. Hyperbole aside, strict naturalism functions (at least within origins research) to close off legitimate lines of inquiry and avenues of potential explanation. It, therefore, limits the ability of scientists to pursue the truth wherever, and perhaps, to whomever, it might lead. (Meyer, 1998, para.22)

Referring to the Darwinian theory of natural selection, Popper does not count it as science but as "a successful metaphysics research programme", because, according to Popper, it is unfalsifiable (Popper, 1985, p. 242). Asimov criticizes this position, claiming that the Darwinian theory of evolution is, in fact, falsifiable. He gives the example of attempts to falsify the theory of evolution through applications of the second law of thermodynamics to show that the evolutionary process is impossible. This argument is not widely accepted, as this interpretation of the law is at the kindergarten level (Asimov, 1993, pp. 278-279). However, this shows that Darwinian theory can be challenged, which means that it is possible that it will be falsified one day in the future.

Moreover he emphasizes that evolutionary theory is not perfect and has been improved and changed since Charles Darwin first formulated it.

> Because the evolutionary view is not perfect and is not agreed upon in every detail by all scientists, creationists argue that evolution is false and that scientists, in supporting evolution, are basing their views on blind faith and dogmatism. … Scientists have been adjusting and modifying Charles Darwin's suggestions since he advanced his theory of the origin of species through natural selection back in 1859. (Asimov, 1993, p. 278)

If we trace back to the period when Darwin's *Origin of Species* was published, we will see that his proposal of the theory of natural selection changed the way people believed. Many people have since altered their beliefs about the origins of living things from divine creation to the theory of natural selection. Popper notices this, as he mentions that, "It is almost unbelievable how much the atmosphere changed as a consequence of the publication, in 1859, of the *Origin of Species*. ... Our whole outlook, our picture of the universe, has changed, as never before," (Popper, 1985, p. 240). This, for me, is a kind of falsification, as the new theory defeated old knowledge. Even though the theory of evolution has not gained full consensus, as some people may still hold to the notion of divine creation, at least the majority have changed their way of thinking to conform to the theory of natural selection. The picture of the world in the community has changed.

Moving to the application of falsification in other areas, throughout the book *The Black Swan*, Taleb (2008, pp. 1-305) expresses his ideas on uncertainty. The "black swan" is a symbol of what we think is improbable but, eventually, turns out to be the case. The black swan represents events around the world that we had never expected. The discovery of a black swan would surprise the world and could change the world. It would change belief. An emerging black swan is evident when telling people that what they think they know is wrong. This also includes the possibility that the black swan might awaken people from what they do not know, from their ignorance. Taleb emphasizes the significance or impact of the black swan on the world. His concept is comparable to Popper's concept of falsification.

Popper and Taleb are the same in thinking that there is no absolute certainty. The difference is that whereas Popper thinks that only science has the characteristic of falsifiability, Taleb suggests that there is no certainty in any notion or belief. He gives black swan stories in various areas as examples. Social agendas, ways of life, political systems, economies, businesses practices, religious beliefs, and so on can change. All knowledge that people adhere to has the possibility of being falsified or changed. He classifies circumstances into two groups by the ease with which a black swan event could occur. The mediocristan in which it would be difficult for a black swan story to occur; and extremistan, in which it would be easy for a black swan story to occur. However, he acknowledges that successful black swan stories can occur in mediocristan circumstances as well (Taleb, 2008, pp. 26-37).

Successfull falsification is the replacement of an old notion with a new idea. This process is the same as a change in the way that people think. This process should not be limited to science as the only field that could develop with this discipline. For example, in the economic community, there was a belief that developed countries, having a surplus in their balance sheets, normally lend money to developing and less developed countries. This theory has been falsified by actual events. The United States, the largest economy in the world, would, by this theory, be sharing their prosperity with developing and underdeveloped countries. In some ways, it contradicts previous economic theory that the US has asked for huge loans from China, the less developed country. Moreover, the US has encountered problems of trade deficits with various countries, especially China. This situation has led to a problematic global imbalance. This problem has also impacted to a certain degree the current economic crisis beginning in 2009 in the US. The consequences of this crisis may change economic theory and even the real economic structure of the world system. For example, the US dollar may loose its status as the global reference currency. Willett et al., (2004, pp. 25-26) have shown that following the earlier Asian crisis of 1997, observations of international capital flows have falsified many economic hypotheses initially invoked to explain the crisis.

In social and political matters, I have argued, falsification also comes into play. The falsification of Marxist theory, in that it predicts the fall of capitalism that never occurred, is one example. Marx predicted that socialism would triumph in the end, but what has occurred is rather its decline. There have been many cases in which societies have been reformed and in which existing political, economic and social systems have been brought down, or at least challenged, by a new concept.

Falsifiability is also applied in the field of management. Shareef (1997, p. 655) is interested in organizational change, and he applied Popper's concept of falsification to the study of the phenomena of organizational change. He argues that changes occur rapidly in innovative organizations and in ways that are congruent with Popper's model. He maintains that, "The application of Popper's philosophy of science to the study of change in innovative organizations allows major stakeholders to question basic assumptions about managing innovative enterprises," (Shareef, 1997, p. 666).

Innovative organizations can utilize the process of trial and error, or the strategy of conjecture and refutation, to help policymakers in making decisions for the improvement of the organization. Shareef gives the example of utilizing a trial and error methodology to enhance the efficiency of the American railway system.

> Several theoretical models were designed and the Southern Railway Company was chosen as the testing ground for theory implementation and evaluation. The theory that best enhanced rail terminal operations efficiency would be

used to trigger organization change processes within the industry. (Shareef, 1997, p. 664)

This example manifests the defect in using falsifiability as the criterion of demarcation between science and non-science. Economic, political, social, management, and even metaphysical knowledge can also be falsified; they can be open to change. There is no knowledge that can be claimed as absolute. It is obvious that throughout time, every kind of knowledge has developed, no knowledge is static; at least some of the concepts have changed. Just as for scientific knowledge, all these other types of knowledge can also grow through falsification.

The notion that only science is falsifiable and the claim that non-science is not, limits the power of falsifiability in contributing to the growth of human knowledge. Falsifiability directly connects to the development or the growth of knowledge. Knowledge that is not falsifiable would be static; it could not develop. The discipline of falsification should be cultivated in all branches of knowledge. The more we find defects in existing notions, the more we can improve them, and that will elevate our knowledge to higher levels, and yield a better understanding of our lives and our world.

For the above reasons, I see no significance in the requirement to demarcate science from non-science. It is not worth the effort trying to make a distinction between science and other endeavors. My position is similar to Laudan's. According to Laudan, it is not important to attend to the methodologies that science uses to acquire knowledge; insofar as a method solves the problem at hand, it contributes to the world (Laudan, 1978, p. 12). Similarly, insofar as it contributes to progress, it contributes to human existence. It is not only science that progresses. While science has grown through the falsification, other disciplines can also grow in the same manner.

In summary, I argue that we should abandon the attempt to demarcate science from non-science, as the effort contributes nothing. The old warfare between science and non-science should cease and the game change from trying to demarcate science from non-science to concentrating on the search for defects in all existing knowledge and attempting to change it for better knowledge. What we should attend to is the growth of knowledge, and that is not limited to science. Falsification, especially in the aspect of challenging existing knowledge and looking for better knowledge, is an excellent tool, teaching people to think differently. This corresponds to Popper's intentions in that he admires those who dare to think differently from the norm, against socially accepted knowledge; he calls this "boldness" (Popper, 1974, p. 978). The discipline of falsification leads to change and change can bring progress. This approach is applicable to all branches of knowledge, and the attempt will earn a bonus in progress and development.

Chapter 6

Conclusion

The growth of knowledge is the most desirable feature of the scientific community. The question how science grows, inquires into the methodologies that contribute to the growth of science, and is a key issue with which many philosophers of science have grappled. One influential school of thought, logical positivism, believes that science grows through a methodology of verification and they therefore take verifiability as the criterion of demarcation between science and non-science. Popper proposes an opposing model. He argues that science rather grows through falsification and that, therefore, falsifiability should be seen demarcating science from non-science (Popper, 2000b, pp. 40-42).

It is logical for Popper to reject the usage of the principle of verification both as the standard methodology of scientific inquiry and as the solution to the problem of demarcation. The problem of induction convincingly prevents the verification of truth, and consequently we cannot use a discipline of verification in the search for truth. But that means also the failure of the principle of verification as the criterion of demarcation. If we cannot verify theories or propositions, how can we use verifiability as the criterion of demarcation? Given the problem of induction, the verifiability criterion forces what are normally considered scientific propositions into the category of non-science, along with metaphysical propositions, because they too are, finally, unverifiable. Thus it is an obvious conclusion that the principle of verification is not appropriate as the criterion of demarcation.

Taking falsifiability as the criterion seems to be an advance over verifiability in that it resolves the problem of induction: there is no need to verify propositions, only to attempt to falsify them.

Popper's philosophy has introduced a new discipline into investigations aimed at producing a growth model of science. For Popper, scientific knowledge is open to falsification, and scientists should be attentive to what is false in theories. A falsification methodology can be effectively applied in the search for better knowledge. Falsification provokes us to search for what specifically is false in a theory or in a particular body of knowledge, and to attempt to improve or develop it, bringing it closer to the truth, although even then we cannot claim to have found ultimate truth. More refutation brings us closer to truth (Popper, 2000a, p. vii-ix).

Many philosophers of science have criticized the principle of falsification as Popper articulates it, but that principle, especially the argument that science can grow through the practice of falsification seems to withstand such critiques. Kuhn, Lakatos, Quine, Feyerabend, and Laudan are significant philosophers of science who criticize Popper's ideas, proposing alternative models of the growth of science.

Kuhn thinks that science is not as open or as easy to change as Popper believes, but rather that revolutions in science are difficult and rare; science, he argues is a closed world. Kuhn argues that there is no falsification in science, but that small defects in theories are merely imperfections that call only for minor modifications. He argues that in any given period, the scientific community has a certain paradigm, the "normal paradigm", that governs the notions held by scientists. A revolution in science succeeds only in case members of that community accept a new paradigm and abandon the prior, normal, paradigm. This process he calls a “paradigm shift” (Kuhn, 1970, pp. 10-42).

Lakatos rejects “naïve falsification”, but accepts “sophisticated falsification”. A counter-example alone should not naïvely be assumed to falsify a theory. The theory will be falsified only when an alternative theory has more corroborating evidence than the previous theory. He argues that falsification is not the only way in which scientific knowledge develops. For him, science can also grow through the extension of the explanatory power of the “research program”. When faced with a counter-example, it is not necessary to reject the whole theory; the problem may be in “auxiliary hypotheses”, which, then, require modification, while core of the theory remains valid (Lakatos, 1995, pp. 100-114).

Quine argues we cannot test any single theory independently, as in reality it is surrounded by many factors that could affect the results of any test. This means that a seemingly falsifying example may not be a result of a defect in the theory; it may rather be that something in the environment caused the inconsistent result. According to Quine, then, falsification is not necessary to the growth of science. He argues rather that science is grown through a process of readjustments or revisions of theories (Quine, 1992, pp. 12-16).

Feyerabend argues that there is no absolute methodology that can be counted as the only method contributing to the growth of knowledge. He argues that scientists use whatever methods are capable of delivering achievement or development. Feyerabend’s is actually close to Popper’s concept. For him, science grows through the development of knowledge, which, in turn, is the result of new theory that clashes with and defeats existing theory (Feyerabend, 2001, pp. 1-11).

Laudan criticizes the notion that any specific methodology is applicable only to science, including the principle of falsification. He suggests specific methods of inquiry are less significant than is the issue of resolving problems. His philosophy of science is a "problem-oriented" theory. Insofar as a method may contribute to resolving problems it is worthy to be used in inquiry for the growth of science (Laudan, 1978, pp. 12-44).

I argue that all these models of the growth of science are similar to Popper's model, based on the principle of falsification. For all of these philosophers of science, Popper, Kuhn, Lakatos, Quine, Feyerabend, and Laudan, the growth of knowledge begins with a counter-example, the failure of a prediction, a problem, or curiosity over the explanatory power of a theory. Following that, there is combat between existing theory and newly proposed theory, which may be an adjusted version of the existing theory. Knowledge progresses when the new theory defeats the old. In contrast, if the new theory cannot marshal sufficient corroborative evidence to overwhelm the existing theory, the old theory maintains its position. These processes could not occur if there were no falsifiability characteristic of knowledge.

Although a counter-example may betray only a small defect in the theory and may not invalidate whole theory, I take it that the theory nevertheless fails to explain the situation. No matter how small or large an adjustment it calls for, it informs us that the theory has been falsified. I think that there is no theory that has gone without correction. There is no theory for which falsification is impossible. The progress of science begins with a provoking event, example, or idea that contradicts what the theory implies, or with the lack of knowledge and the desire to replace ignorance with knowledge. This means that the discipline of falsification is very significant in the progress of knowledge and scientific discovery. The falsifiability characteristic of knowledge means that it is open to change. Without this characteristic, knowledge would never change. Although we cannot claim that all change brings about progress, if there were no change there would be no opportunity for progress.

Therefore a mistake in scientific knowledge does not sin against, but rather contributes to, the growth of scientific knowledge. When scientific knowledge can be falsified, that means that it is possible for a scientist to discover that his notions can also be falsified. In other words, he may discover that he has made a mistake. How then should the scientist react to his mistake? Hawking suggests that we should admit it when we find that we have made mistakes for the sake of later study, preventing confusion and misunderstanding of the topic and contributing much to human knowledge. Hawking accepts his mistake in surmising that during a contraction of the universe, the arrows of time would be reversed:

> I realized that I had made a mistake: the no boundary condition implied that disorder would in fact continue to increase during the contraction. The thermodynamic and psychological arrows of time would not reverse when the universe begins to recontract or inside black holes. (Hawking, 1988, p. 167)

He adds another example of a great scientist accepting his own mistake, "A good example of this was Einstein, who called the cosmological constant, which he introduced when he was trying to make a static model of the universe, the biggest mistake of his life" (Hawking, 1988, p. 168). If we find a mistake in our knowledge, that provides good opportunity to improve our knowledge and to be led closer to the truth.

Although I support Popper's model, in that the discipline of falsification is part of the progress of knowledge, I argue that falsifiability is neither appropriate nor valid as the criterion of demarcation between science and non-science. Falsifiability fails to demarcate science from metaphysics. There are many cases throughout human history in which prior metaphysical beliefs have been falsified after the technology became available permitting those beliefs to be tested. In ancient times epidemics were typically attributed to evils or bad spirits. But today, with advanced technology, we have microscopes to see that disease is caused by bacteria and viruses. This means that the old belief has been falsified. Hence, I conclude that metaphysics is in the same category with science, according to the falsifiability criterion. The difference may be only that we do not yet know how to falsify today's metaphysical theories. In the future, it may well be that what we now consider metaphysics will come to be testable as scientific theory.

Though I prefer the discipline of falsification when applied to the pursuit of knowledge, falsification as Popper construes it has the weakness that, because of alternative explanations for counter-examples, it is very difficult to find conclusive falsification, (Stiver, 1996, p. 47). In addition, Popper's own argument that we cannot achieve truth could imply that we also cannot claim conclusive falsification. However, this is still in line with the model of knowledge as open to challenge and change.

Moreover, I fear that using falsification as the criterion of demarcation between science and non-science, limits the discipline of falsification to science alone. This is to limit the contribution that falsification could make to other endeavors. The falsifiability character of knowledge is important in that it implies openness to change. It is not only science that can be changed or falsified, but also all other modes of knowledge. For instance, politics, economics, and social knowledge can also be falsified. Popper himself applies his philosophy of science to his political and social philosophy. He criticizes the social and political concepts of Plato and Marx and advocates instead the concept of an open society. This is a good example, showing that even a political notion can be challenged, changed, and falsified. Epistemologically, the political theories of Plato and Marx are challenged, and Popper proposes an alternative directed at falsifying their beliefs. Practically, the political system in any society or country can change to some other system, as we have seen many times in history.

In summary, the principle of falsification as articulated and advocated by Karl Popper is very beneficial, especially in its contribution to the growth of knowledge. This discipline encourages people to search for counter-examples and for defects in prior knowledge and to attempt to improve existing knowledge or to find other, rival knowledge that gives more appropriate answers. This brings with it the advancement of knowledge. Nonetheless, Popper has made a mistake in restricting falsifiability to science alone. Falsifiability cannot function to delimit science from non-science, as it is not only scientific knowledge that can be falsified. The discipline of falsifiability can apply to all kinds of knowledge and should not be limited to science. We should exploit the power of falsification to teach people to think differently from how they have dogmatically been thought to think. Limiting falsifiability to science limits creativity, inventiveness, innovation and also imaginative power, while in fact that limitation is not the case in practical life.

Reference

Primary Sources

Popper, K. R. (1974). "Karl Popper: Replies to My Critics". in Schilpp, Paul A., (ed.). *The Philosophy of Karl Popper: The Library of Living Philosophers.* (pp. 961-1,197). Illinois: The Open Court Publishing Co.

Popper, K. R. (1979). *Objective Knowledge: An Evolutionary Approach.* (revised ed.). (1972). New York: Oxford University Press.

Popper, K. R. (1981). "The Rationality of Scientific Revolutions". in Hacking, Ian., (ed.). *Scientific Revolution.* (pp. 80-106). New York: Oxford University Press.

Popper, K. R. (1985). "Natural Selection and Scientific Status". in Miller, David., (ed.). *Popper Selections.* (pp. 239-246). New Jersey: Princeton University Press.

Popper, K. R. (1985). "The Growth of Scientific Knowledge". in Miller, David., (ed.). *Popper Selections.* (pp. 171-180). New Jersey: Princeton University Press.

Popper, K. R. (1993). "Falsification". in Huchingson, James E., (ed.). *Religion and the Natural Sciences: the Range of Engagement.* (pp. 142-147). Florida: Harcort Brace College Publishers.

Popper, K. R. (1999a). *All Life is Problem Solving.* London: Routledge

Popper, K. R. (1999b). *The Open Society and Its Enemy: Volume I Plato*. (5th ed.). (1966). London: Routledge

Popper, K. R. (1999c). *The Open Society and Its Enemy: Volume II The High Tide of Prophecy: Hegel, Marx, and The Aftermath*. (5th ed.). (1966). London: Routledge

Popper, K. R. (2000a). *Conjectures and Refutations*. (5th ed.). (1989). London: Routledge

Popper, K. R. (2000b). *The Logic of Scientific Discover*. Cornwall: TJ International Ltd.

Other Books

Anderson, H . (2001). *On Kuhn*. Belmont, CA: Thomson Learning, Inc.

Barbour, I. G. (1997). *Religion and Science: History and Contemporary Issues*. New York: HarperCollins Publishers

Brown, H.I. (1990). *Rationality*. London: Routledge.

Draper, J. W. (1881). *History of the Conflict between Religion and Science (Electronic Version)*. New York: D. Appleton and Company

Fetzer, J. H. (1993). *Philosophy of Science*. New York: Paragon House

Feyerabend, P. (2001). *Against Method*. (3rd ed.). New York: Veso

Gellner, E. (1979). *Legitimation of Belief*. Oxford: The Press Syndicate of the University of Cambridge

Gillies, D. (1993). *Philosophy of Science in the Twentieth Century.* Oxford: Blackwell Publishing

Hamlyn, D. W. (1990). *The Penguin History of Western Philosophy* . London: Penguin Books Ltd.

Hausman, D. M. (1994). *The Philosophy of Economics an Anthology.* (2nd ed.). Melbourne: The Press Syndicate of the University of Cambridge

Hawking, S. (1988). *A Brief History of Time from the Big Bang to Black Holes.* London: Bantam Press

Hunnex, M. D. (1986). *Chronological and Thematic Charts of Philosophies & Philosophers.* Michigan: Zondervan Publishing House

Klemke, E.D., Hollinger, R. & Kline, A.D. (1980). *Introductory Readings in the Philosophy of Science.* New York: Prometheus Books

Kuhn, T. S. (1970). *The Structure of Scientific Revolutions* (2nd ed.). Chicago: The University of Chicago Press

Laudan, L. (1978). *Progress and Its Problems towards a Theory of Scientific Growth.* California: University of California Press, Ltd.

Mortan, A. (2004). *A Guide through the Theory of Knowledge.* (3rd ed.). Victoria: Blackwell Publishing

Notturno, M. D. (2003). *On Popper.* Canada: Thomson Learning, Inc.

Okasha, S. (2002). *Philosophy of Science: A Very Short Introduction.* New York: Oxford University Press.

Quine, W.V. (1992). *Pursuit of Truth.* Harvard University Press

Quine, W.V. (1980). *From A Logical Point of View, Nine Logico-Philosophical Essays.* (revised 2nd ed.). London: Harvard University Press

Rozenberg, A. (2000). *Philosophy of Science A Contemporary Introduction.* London: Routledge.

Salmon, M.H., Earman, J., Glymour, C., Lennox, J.G., Machamer, P., McGuire, J.E., et al. (1992). *Introduction to the Philosophy of Science*. New Jersey: Prentice-Hall, Inc.

Sinclair, J (Ed.). (2006). *Collins Cobuild Advanced Learner's English Dictionary* (5th ed.). Glasgow: HerperCollins Publishers.

Stiver, D. R. (1996). *The Philosophy of Religious Language: Sign, Symbol, and Story.* Cambridge: Blackwell Publishers Inc.

Strickland, S. & Strickland E. (2006). *The Illustrated Timeline of Science*. New York: Sterling Publishing Co., Inc.

Taleb, N. N. (2008). *The Black Swan – The Impact of the Highly Improbable* . London: Penguin Books Ltd.

White, A. D. (1898). *A History of the Warfare of Science with Theology in Christendom (Electronic Version*). New York: D. Appleton and Company

Wittgenstein, L. (1922). *Tractatus Logico-Philosophicus (Electronic Version*). Retrieved October 16, 2008, from http://www.voidspace.org.uk/psychology/wittgenstein/tractatus.shtml

Articles

Asimov, I. (1993). "The "Threat" of Creationism". in Huchingson, J.E. (ed.). *Religion and the Natural Sciences: the Range of Engagement.* (pp. 275-284). Florida: Harcort Brace College Publishers.

Bronowski, J. (1974). "Humanism and the Growth of Knowledge". in Schilpp, P. A. (ed.). *The Philosophy of Karl Popper: The Library of Living Philosophers.* (pp. 221-240). Illinois: The Open Court Publishing Co.

Childs, R. Jr. (1976). "Karl Popper's The Open Society and Its Enemies: A Critique". (Electronic Version). *Libertarian Review,* 5(5), Retrieved December 12, 2008, from http://www.libertarian.co.uk/lapubs/polin/polin083.pdf

Feyerabend, P. (2004). "Consolations for the Specialist". In O'here, A. (ed.). *Karl Popper: Critical Assessments of Leading Philosophers* (vols.2). (pp. 257-289). London: Routledge

Flew, A. (1968). "Theology and Falsification," in Joel F. (ed.), *Reason and Responsibility: Readings in Some Basic Problems of Philosophy.* (pp. 48-49). California: Dickenson Publishing Company,

Gieryn, T. F. (1983). "Boundary-Work and the Demarcation of Science from Non-Science: Strains and Interests in Professional Ideologies of Scientists". *American Sociological Review.* 48 (6), 781-795.

Grunbaum, A. (2004). "The Degeneration of Popper's Theory of Demarcation". in O'here, A. (Ed.). *Karl Popper: Critical Assessments of Leading Philosophers* (vols. 2). (pp. 392-411). London: Routledge

Hempel, C. G. (2001). "Scientific Rationality: Normative versus Descriptive Construals". in Fetzer, J. H. (Ed.). *The Philosophy of Carl G. Hempel: Studies on Science, Explanation, and Rationality.* (pp. 357-371). New York: Oxford University Press

Kneale, W. C. (1974). "The Demarcation of Science". in Schilpp, P. A. (ed.). *The Philosophy of Karl Popper: The Library of Living Philosophers.* (pp. 205-217). Illinois: The Open Court Publishing Co.

Kneale, W. C. (2004). "Scientific Revolution for Ever?". in O'here, A. (ed.). *Karl Popper: Critical Assessments of Leading Philosophers* (vols. 2). (pp. 437-451). London: Routledge

Kraft, V. (1974). "Popper and the Vienna Circle". in Schilpp, P. A. (ed.). *The Philosophy of Karl Popper: The Library of Living Philosophers.* (pp. 185-204). Illinois: The Open Court Publishing Co.

Kuhn, T. S. (2004). "Logic of Discovery or Psychology of Research". In O'here, A. (ed.). *Karl Popper: Critical Assessments of Leading Philosophers* (vols.2). (pp. 235-256). London: Routledge

Lakatos, I. (1974). "Popper on Demarcation and Induction". in Schilpp, P. A. (ed.). The *Philosophy of Karl Popper: The Library of Living Philosophers.* (pp. 241-273). Illinois: The Open Court Publishing Co.

Lakatos, I. (1995). "Falsification and The Methodological of Science Research Programmes". in Lakatos, I. & Musgrave, A. (eds.). *Criticism and The Growth of Knowledge.* (pp. 91-196). New York: Cambridge University Press

Maxwell, G. (1974). "Corroboration without Demarcation". in Schilpp, P.A. (ed.). The *Philosophy of Karl Popper: The Library of Living Philosophers.* (pp. 292-321). Illinois: The Open Court Publishing Co.

Maurer, R. W. (2004). "Falsification of Theories without Verification of Basic Statements – An Argument for the Possibility of Knowledge Growth". Retrieved October 16, 2007, from http://philsci-archive.pitt.edu/archive/00002188/01/ Falsification_of_ Theories_without_Verification_of_Basic_Statements_PhilSci.pdf

Medawar, P. (1974). "Hypothesis and Imagination". in Schilpp, P. A. (ed.). The *Philosophy of Karl Popper: The Library of Living Philosophers.* (pp. 275-291). Illinois: The Open Court Publishing Co.

Meyer, S. C. (1994). "The Use and Abuse of Philosophy of Science: Response to J.P. Moreland". (Electronic Version). *Perspectives on Science and Christian Faith.* 46(1), Retrieved April 16, 2008, from http://www.arn.org/docs/meyer/sm_moreland.htm

Putnam, H. (1974). "The "Corroboration" of Theories". in Schilpp, P. A. (ed.). *The Philosophy of Karl Popper: The Library of Living Philosophers.* (pp. 221-240). Illinois: The Open Court Publishing Co.

Quine, W.V. (1974). "On Popper's Negative Methodology". in Schilpp, P. A. (ed.). *The Philosophy of Karl Popper: The Library of Living Philosophers.* (pp. 218-220). Illinois: The Open Court Publishing Co.

Shapere, D. (1981). "Meaning and Scientific Change". in Hacking, I. (ed.). *Scientific Revolution.* (pp. 30-59). New York: Oxford University Press. .

Shareef, R. (1997). "A Popperian View of Change in Innovative Organizations". *Human Relation.* 50 (6), 655-670.

Singer, P. (1974). "Discovering Karl Popper". *The New York Review of Books, 21(7).* Retrieved October 16, 2007, from http://www.nybooks.com/articles/9252

Willett, T.D., Budiman, A., Denzau, A., Jo G., Ramos, C. & Thomus, J., (2004). "The Falsification of Four Popular Hypotheses About the Asian Crisis". *The World Economy.* 27(1), 25-43.

Winch, P. (1974). "Popper and Scientific Method in the Social Sciences". in Schilpp, Paul A., (ed.). *The Philosophy of Karl Popper: The Library of Living Philosophers.* (pp. 889-904). Illinois: The Open Court Publishing Co.

Wisdom, J. (1983). "Gods". in Klemke, E.D. (ed.), *Contemporary Analytic and Linguistic Philosophies.* (pp. 338-352). New York: Prometheus Books,

Worral, J. (2004). " 'Revolution in Permanence' Popper on Theory-Change in Science". In O'here, A. (ed.). *Karl Popper: Critical Assessments of Leading Philosophers* (vols.2). (pp. 488-512). London: Routledge