Learning and Computers

by

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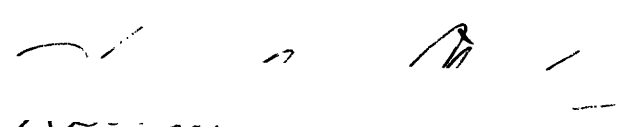
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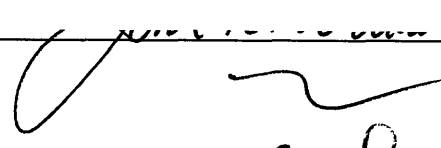
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ABSTRACT:

A theoretical examination of the epistemological presuppositions of current educational practice is presented and contrasted with the Genetic Epistemology of Jean Piaget. Piaget's theory holds that the neophyte builds knowledge by subjecting previously established knowledge to an interaction with the environment. New objects are assimilated to current knowledge structures and the knowledge structures are accommodated to the objects. This proposition of Genetic Epistemology constitutes a particular formulation of a more general method of knowledge construction through an active process of hypothesis generation and hypothesis testing.

A survey of the history of technological development from primitive society to the beginnings of modern chemistry and physics demonstrates that, in the absence of definite information, humans have a propensity for generating hypothesis when faced with novel occurrences. These hypotheses may be more or less fantastic in form. Modern day children exhibit a tendency to generate explanations of natural events which reveal a tendency for animism. These explanations are initial working hypotheses. The implications for education are two-fold. The neophyte approaches a novel problem with a history of hypotheses generated in the absence of scientific explanation. These constitute the subject's beliefs and prejudices. If these beliefs contradict the new information and they are not addressed at their own level, they may hinder the learning process. The second implication is that learning through hypothesis generation and hypothesis testing may be more effective than the more traditional method of instruction which consists of a top down presentation of material. This theme is further considered in the light of the scientific methodology. Karl Popper's suggestion that science progresses through a process of conjecture and refutation provides addition evidence for the central thesis. Another implication of this is that if scientists are trained through hypothesis generation and testing, they receive implicit training on method.

Computers can be used to facilitate such a training method. Virtual laboratories, that are more or less constrained, could be constructed to allow students to conduct experiments quickly, easily, and safely. Simulation would facilitate the testing and elimination of hypotheses as necessary, and knowledge structures could be built through a process of conjecture and refutation.

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LEARNING AND COMPUTERS

A Preliminary Study For a Potential Role for Computers in Education

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CONTENTS

CHAPTER ONE

Learning Through Interaction

"We ought, he says, to be neither like spiders, which spin things out of their own insides, nor like ants, which merely collect, but like bees, which both collect and arrange. This is somewhat unfair to the ants, but it illustrates Bacon's meaning."

- Bertrand Russell on Francis Bacon (_History,_ p. 544).

Passive or active? Is the human's mind a simple reflection of the world, are we mere glasses, or are we active explorers of our environment? This is the fundamental question addressed by this thesis.

Are we the mirrors of reality, or as knowing subjects, do we order our experience of the world? Does the old proverb _we learn from experience_ presuppose that experience befalls us, or that we chase it down and force experience to face our questions. Many assume it is the former. Apart from ostensibly providing the most straightforward solution, there are other reasons for harboring such a belief. The element of chance in our daily lives must surely account for a portion of this belief. The idea that we might put experience to the test of our opinions suggests that we have a measure of control over our experiences that many would scarcely concede. The vastness of our ignorance provides another weighty argument in favor of the proposition that the world simply makes its impression upon us. "How," one might wonder, "could a person even begin to learn by posing questions to

Nature. At what aspect of her vast multiplicity should the first question be addressed?" One might well believe that it is first necessary to gain a modicum of knowledge in a new domain before one may even guess at a reasonable question to ask. We could continue to multiply justifications for the belief that we may best learn by watching and listening -- by allowing the world to reveal its secrets to our waiting, quiet, our hungry, minds.

Neither is there a lack of evidence in support of the second view -- that the subject is an active explorer. *We learn by doing* is a common idiom. To a large extent, our educational system uses student exercises as a vital part of the learning process. Both the inquiries of the student in the classroom and the apparent expectancies of the infant testify that, though we may not know the answers in exact detail, we are not without opinions -- we are not without expectancies -- we are not without questions.

The method of classroom teaching that is most prevalent today suggests that the former view, that we are capable of simply absorbing information, holds sway. The classroom situation consists of a top down presentation of observations and facts, theories and explanations. Questions tend to be limited, and when posed, are typically answered by a repetition of an idea or fact mentioned earlier. This may be due to a more or less tacit agreement among educators that assailing a mind with a barrage of information is the most effective method of imparting knowledge. On the other hand, it may simply provide the easiest solution to a difficult problem. Classrooms are large, and teaching staff is limited. Each individual student brings to the task his own personal history -- a (mental) history that, for the most part, is inaccessible to the educator. By resorting to a top down presentation of material, the teacher aims at efficient communication. The current classroom approach may constitute an attempt to provide as much information to as many individuals as possible. However, if the learner is not simply a sponge, then this method may be significantly sub-optimal.

In the main, this inquiry addresses this question. Chapter one introduces the epistemological argument. John Locke provides us with a suitable background for our discussion. As a proponent of the idea that we come into the world completely void of knowledge, and that we learn entirely from experience, he represents the empiricists' view, the view that one's mind, one's knowledge, is the passive reflection of the world. Against this, we raise the transcendental philosophy of Immanuel Kant whose epistemology appears diametrically opposed to Locke's. Our main concern with these philosophers is two-fold. Firstly, their ideas introduce the problem of human knowledge and the early attempts at its solution. Secondly, they provide us with a vantage point from which we may consider the epistemology of Jean Piaget.

While studying the origins of knowledge in children, Jean Piaget expounded the idea that we build our knowledge of the world through active participation. The knowledge structures we already possess go out to meet novel situations. In the process, they are modified, typically toward the end of becoming more appropriate structures for further interaction with that situation. He considered this to be a reciprocal process of assimilation and accommodation. Newly encountered objects are assimilated to a knowledge structure and the structure is modified by it. Assimilation and accommodation may be viewed as a process of hypothesis generation and hypothesis testing. When a subject attempts to assimilate an object to a knowledge structure, he hypothesizes that the object will be amenable to manipulation by that knowledge structure. When the knowledge structure is applied to an object, the structure itself is modified. This constitutes a test of the hypothesis. The proposition that humans explore unknown domains through a process of hypothesis generation and hypothesis testing is explored in the following two chapters.

Chapter two is a historical survey of the propensity of humans to generate hypotheses in the face of the unknown. Our points of departure are Primitive Man, Europeans of the renaissance period, and modern European children. It is interesting that whenever there is

a need for explanation or for action, there is a hypothesis. It is also interesting that these hypotheses are often quite fantastic in form. The implications of this for learning seem to be two-fold. Firstly, if a human has an instinct to generate hypotheses when faced with a novel situation, then these hypotheses should be explicitly addressed -- that is, put to an earlier, rather than later, test. Secondly, the mechanism of building knowledge through hypothesis generation and hypothesis testing may be substantially more powerful that we currently suspect. It may be time to consider these possibilities seriously.

The methods of science are considered in the third chapter. Here we find the most explicit formulation of our central thesis. In his study on the logic of scientific discovery, Karl Popper realized that science itself advances through a process of conjecture and refutation. The researcher develops a hypothesis -- a theory, and then makes a genuine attempt to refute it. If these are the ways of science, then by adapting similar methods in our educational system, we may also benefit by providing our future scientist with implicit training in method. The potential is yet to be explored.

In the light of these considerations, the final chapter considers a potential role for the use of computers in education. As virtual laboratories, which may be programmed to any level of order and constraint, they may provide us with the versatility necessary to make such an approach to education possible. We also consider the appropriateness of the methods suggested here for various aspects of education. It is obvious that the value of these methods may be limited. This is considered in more detail in the final chapter.

Now, let us consider the problem as it was addressed by some of the greatest philosophers of the seventeenth and eighteenth centuries Following this we will examine a twentieth century response to their solutions.

The Philosophical Ground of Modern Epistemology

Introduction

Broadly speaking, modern epistemology may be said to derive from two schools of thought, viz. empiricism and apriorism. John Locke may be considered the father of empiricism (Russell, *History*, p. 609), though he had predecessors in Francis Bacon and Hobbes. His epistemology holds that all our knowledge must ultimately derive from experience. In extending Locke's ideas, David Hume dealt his critical blow to the logical validity of scientific induction. This spurred Immanuel Kant, educated in the rationalist tradition (Russell, *Problems*, p. 83), to attempt (in the face of Hume's skepticism) to answer such questions as: "How is pure mathematics possible?"; and "How is pure natural science possible?" (Kant, *Prolegomena*, p. 24). The result of his inquiry was the epoch making *Critique of Pure Reason*, wherein he states that the intuitions of space and time are given to us *a priori*, along with categories of judgment, such as causality.

Rather than providing us with definitive conclusions, a cursory glance at these two epistemologies will   serve us as an orientation for considering the more modern approaches to learning and knowledge, specifically, the genetic epistemology of Jean Piaget.

John Locke (1632-1704)

John Locke was an empiricist -- he believed that all human knowledge ultimately derives from sense-perception and introspection. In 1690 he published the first edition of his *Essay Concerning Human Understanding*, wherein he hoped to determine 'what objects our understandings were, or were not, fitted to deal with' (Locke, quoted from Copleston, *History Vol. 5*, p. 69).

The intellectual climate of the time was heavily influenced by the rationalist Rene Descartes. Descartes, after applying his method of systematic doubt to everything one may possibly doubt, arrived at the indubitable truth: "I think therefore I am"; and its correlate (Rene Descartes, quoted from Flanagan, p. 11):

> "But what then am I? A thing which thinks. What is a thing which thinks? It is a thing which doubts, understands, [conceives], affirms, denies, wills, refuses, which also imagines and feels."

These functions of the mind are given before experience -- they are inborn -- and they constitute the ultimate source of our knowledge. Experience merely occasions the generation of knowledge by these processes (Gardner, *History*, p. 52). Thus, the mind plays an active role in the *formation* and *organization* of our knowledge, and the nature of this role is determined *a priori*, that is, before and independent of all experience.

Locke begins his *Essay* by rejecting the thesis of innate ideas. He suggests that the argument in its favor, *that there are principles upon which all people agree*, is both incorrect, and even if correct, would not necessitate the existence of innate ideas (Copleston, *History Vol. 5*, p. 74). His position is best captured by (Locke, quoted from Herrnstein and Boring, *History*, p. 584):

> "Let us then suppose the Mind to be, as we say, white Paper, void of all Characters, without any Ideas; How comes it to be furnished? Whence comes it by that vast store, which the busy and boundless Fancy of Man has painted on it, with an almost endless variety? Whence has it all the materials of Reason and Knowledge? To this I answer, in one word, from Experience: In that, all our Knowledge is founded; and from that it ultimately derives itself."

Thus the mind as *tabula rasa*. The experience Locke refers to is our experience of the external world, as given to us by our senses, and our experience of the operations of the mind itself, as given to us by reflection. Of the latter, the mind derives its ideas of "Perception, Thinking, Doubting, Believing, Reasoning, Knowing, Willing, and all the

different actings of our own minds" (*ibid.*, p. 585) through observation of the mind as it operates upon its ideas. That is to say, these ideas are derived from observing the mind perceive, think, doubt, etc., not that these processes are derived from experience. Thus the epistemology of Locke allows for mental processes given *a priori*.

It may be worthwhile to consider the differences between the positions of Locke and Descartes more explicitly. Both allow for innate processes. However, for Descartes, knowledge has its ultimate source in the mind, while for Locke, knowledge has it ultimate source in experience. So, for example, Descartes' mind will generate the idea of parallel lines when occasioned by its own thinking or experiencing, while Locke's mind will abstract the idea of parallel lines from repeated experience of such lines as they are given to our senses.

For Locke, experience is the source of our ideas. But what of the ideas themselves? Locke made the distinction between what he called simple ideas and complex ideas. Of simple ideas he distinguished four classes: ideas of one sense (*whiteness*: vision); simple ideas of more than one sense (*figure*: vision and feeling (physical)); simple ideas of reflection (*thinking*); and simple ideas derived through reflection and sensation (*pleasure, pain*) (Copleston, *History Vol. 5*, p. 79). These ideas are *passively* perceived through sensation and reflection, and percpetion is "the first step and degree towards knowledge, and the inlet of *all* the material in it" (Locke, quoted from Russell, *History*, p. 610). "It is not in the power of the most exalted wit, or enlarged understanding, by any quickness or variety of thought, to invent or frame one new simple idea in the mind, not taken in by the ways aforementioned." (Locke, quoted from Copleston, *History Vol. 5*, p. 80).

Complex ideas are actively framed by the mind through operations performed on a number of simple or simple and complex ideas. Locke spelled out three classes of operation: *combination*; *relation* (comparing without combining); and *abstraction* (separating one idea from the other ideas which accompany it in their real existence). The complex ideas

which may be formed through such operations may be *modes, substances,* or *relations.* *Modes* are complex ideas which depend upon, or affect substances. Drunkenness and hypocrisy are examples of such ideas.

> "[The general idea of *substance* is] nothing but the supposed but unknown support of those [clusters of simple ideas which] we find existing, which we imagine cannot subsist *sine re substante*, without something to support them." (Locke, quoted from Copleston, *History Vol. 5*, p. 91)

The mind itself supplies the idea of a substrate, which it presupposes on encountering recurring clusters of simple ideas. Finally, a *relation* is a complex ideas derived from the operation of relating two ideas. An example of a relational idea is *cause*, as is its concomitant *effect*. The relational idea we call *cause* derives from observing how one idea, e.g. liquid, may be brought into existence by another idea, e.g. the application of heat to ice. Here the heat is considered *in relation to* the transformation of ice to water, and is considered the *cause*, while the appearance of the liquid is considered the *effect.*

While too meager in detail to allow us to consider Locke's epistemology on its own terms, the preceding exposition will provide us with an introduction to the associationist empiricist's approach to knowledge. Simple ideas are received passively, and exclusively, by the mind through perception (sensation and reflection), while complex ideas are actively constructed by the mind through operations performed on other ideas. All complex ideas ultimately derive from simple ideas, and therefore from experience. "Knowledge," according to Locke, "is the perception of the agreement or disagreement of two ideas" (Locke, quoted in Russell, *History*, p. 611). Thus, all knowledge ultimately derives from experience.

Locke's ideas were later picked up and expanded by George Berkeley and David Hume. The result of this extension was radical skepticism -- a position that greatly undermined the authority of any human knowledge. As we shall see later, Hume limited the possibility

of knowledge with certainty to the area of mathematics. This threat to the possibility of real scientific knowledge lead Immanuel Kant to a critical examination of human reason, and an attempt to separate what we can know from what we cannot. The product of his inquiry was *The Critique of Pure Reason*, one of the most influential books in philosophy.

Immanuel Kant (1724-1804)

Before considering the philosophy of Immanuel Kant, it will be expedient to consider the problems to which his efforts were addressed. In particular, it was David Hume's argument against the necessity of a connection between the events which we typically call *cause* and *effect* (Kant, *Prolegomena*, p. 5). It was this, coupled with a firm conviction in the necessary validity of Newtonian Mechanics and Euclidean Geometry, that inspired him to build the philosophical monument he offers us in his *Critique of Pure Reason*.

David Hume

David Hume (1711-1776) was an empiricist in the tradition of John Locke and George Berkeley. Hume, however, distinguished himself from Locke and Berkeley in that he did not shrink, but pushed his philosophy to its logical conclusion. In the opinion of Bertrand Russell, the result was self-consistent, but incredible, and something of a philosophical dead end (Russell, *History*, p. 659). Be that as it may, he made explicit many of the tacit consequences of empiricism, severely undermined the metaphysical notion of causality, and demonstrated, with clarity and simplicity, that the certainty of the results obtained by employing induction could not be supported logically.

The contents of the mind Hume calls perceptions, and these he divides into two classes: *impressions* and *ideas*. By impressions he means immediate sensation, and by ideas, thoughts in general (Hume, *Inquiry*, p. 27). In this theory the notion of the association of is central: ideas tend to call up one another with a certain degree of regularity (*ibid.*, p.

31). His system holds that there are only three principles of association: *resemblance, contiguity,* and *causation.*

Hume felt that the objects of human reason were of two kinds: *relations of ideas* and *matters of fact.* Geometry, algebra, arithmetic, and every relation which is intuitively or demonstratively certain are of the first kind. These relations are objects of pure thought, and rely only upon the ideas they connect. They require nothing outside of the mind for their confirmation (*ibid.,* p. 40).

Matters of fact, on the other hand, rely solely upon the testimony of our senses and memory, and therefore do not attain certainty after the manner of relations of ideas. Hume argues that "all reasoning concerning matter of fact seem to be founded on the relation of *cause* and *effect*" (*ibid.,* p. 41). Because the mind experiences the constant conjunction of event A (called *cause*) and event B (called *effect*), it assumes a necessary connection (*causality*). However, the belief that in the future experience of A will continue to be conjoined with experience of B presupposes that the future will resemble the past. This requires that nature be uniform. But the uniformity of nature is not a logical necessity. Therefore, the notion that the past will resemble the future -- expedient as it may be -- is not a logical necessity.

That nature is not uniform means that all knowledge which depends upon experience for its validation, is not certain, but only probabilistic. Also, causality, as it is known to the understanding, is not a necessary connection between events, but merely a belief founded upon the past experience of the constant conjunction of events. The belief in the necessary connection between 'cause' and 'effect' is merely due to custom, it is a habit (*ibid.,* p.56).

Kant's Answer

Hume's skepticism insists that we have no evidence of a necessary connection between events we call *causes* and events we call *effects*. Thus, causality is merely a supposition formed through habit. Since the thesis that nature is uniform cannot be logically supported, knowledge derived solely through induction is not apodictic. Consequently the laws of nature cannot be known with absolute certainty.

Mathematics escaped Hume's skepticism because, according to Hume, mathematical propositions are analytic. That is, the predicate contains no more information than is already contained in the subject. "A square is a figure with four equal sides," is an analytic judgment -- "four equal sides" is already contained in the concept of "square". In a synthetic proposition on the other hand, the predicate amplifies the subject. "The color of the table is brown," is a synthetic proposition -- browness is not already contained in the concept called "table." Hume maintains that all synthetic judgments rely entirely upon experience for their confirmation. All physics and metaphysics require synthetic judgments which rely upon experience. Consequently they cannot be known with certainty. Thus, physics and metaphysics are not apodictic sciences, as mathematics is.

Kant was not of Hume's opinion that mathematical propositions are analytic. In the *Prolegomena to Any Future Metaphysics* he gives an example from geometry. "That a straight line is the shortest path between two points is a synthetic proposition. For my concept of straight contains nothing of quantity, but only a quality" (Kant, *Prolegomena*, p. 14). Since mathematical propositions are synthetic[1], and are given *a priori* (independent

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[1] Bertrand Russell states (*History*, p. 716): "The transcendental (or epistemological) argument is best stated in the *Prolegomena*. Geometry, as we now know, is a name governing two different studies. On the one hand, there is pure geometry, which deduces consequences from axioms, without inquiring whether the axioms are "true"; this contains nothing which does not follow from logic, and is not "synthetic," and has no need of figures such as are used in geometrical text-books. On the other hand, there is geometry as a branch of physics, as it appears, for example, in the general theory of relativity; this is an empirical science, in which the axioms are inferred from measurements, and are found to differ from Euclid's. Thus

of experience), then synthetic propositions *a priori* are possible. Kant then poses the question: "How are synthetic propositions *a priori* possible" (*ibid.*, p. 21).

The first part of this main transcendental question is "How is pure mathematics possible" (*ibid.*, p. 25). In answering this question, Kant makes the distinction between what he calls the *noumenal world* and the *phenomenal world*. The thing-in-itself exists in the noumenal world. Our experience of the thing-in-itself is phenomenal. Kant claims that we have no access to the noumenal world, except as it presents itself to us in experience. Thus we can only know the reflection of a thing in the phenomenal world, we can never know the thing-in-itself.

The objects of experience (phenomena) are arranged according to the intuitions of space and time. "Intuition" is the common translation of Kant's German *"anschauung,"* which literally means "looking at" or "view" (Russell, *History*, p. 708). So for Kant, space and time are not concepts. Rather, they are the forms of intuition, and all experience is arranged according to these forms. Now, since our only experience of the external world is through the intuitions of space and time, the question: *"How are the synthetic propositions of geometry a priori possible?,"* has a straight-forward answer. Geometry completely describes the intuition of space -- thus all the objects of experience must, *a priori*, obey the rules of geometry. We cannot know whether of not the propositions of geometry apply to the noumenal world, but we can know that all objects of experience (phenomena) must conform to these propositions -- and this we know with certainty.

Despite Hume's refutation of the possibility of apodictic propositions derived from experience, Kant believed that Nature was necessarily ruled by the laws of physics (Kant, *Prolegomena.*, p. 38):

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of the two kinds of geometry one is *a priori* but not synthetic, while the other is synthetic but not *a priori*. This disposes of the transcendental argument."

"We nonetheless actually posses a pure natural science in which are propounded, *a priori*, and with all the necessity requisite to apodictic propositions, laws to which nature is subject"

So the second part of Kant's main transcendental question is "How is pure natural science possible?" (*ibid.*, p. 38). Kant asks whether judgments of experience may be given *a priori*? To this he answers in the affirmative. How is this possible? The objects of experience, as presented to the understanding through the intuitions (*anschauung*) of space and time, are all subsumed under the concepts of the understanding -- "concepts which have their origin quite *a priori* in the pure understanding, and under which every perception must first of all be subsumed and then by their means changed into experience" (*ibid.*, p. 41). There are 12 concepts of pure understanding, of which causality is one example. Hume maintains that causality is merely the name given to an expectation that may be attributed to habit. Kant replies that causality is a precondition of all experience. Hume claims that the proposition "*for every effect there is a cause*" cannot be apodictic, because the proposition is derived from experience. Kant answers that the proposition is indeed apodictic, and given *a priori*, because all experience is subsumed under the concepts of the understanding -- i.e. the proposition "*for every effect there is a cause*" is a precondition of experience itself.

The third part of the main transcendental question, as addressed in the *Prolegomena*, concerns the possibility of metaphysics as a science. Since our primary concern with Kant is epistemological, his discussion on metaphysics is not immediately relevant to the current discussion. The main idea I wish to draw from Kant's philosophy is that all experience is ordered according to the forms of intuition and the concepts of the understanding, and these are given *a priori*. In other words, experience is not the passive reflection of the world in the mind, it is the result of the mind's active ordering of the objects of experience; and this ordering proceeds according to rules which are not derived from experience, but are preconditions of experience itself. By way of analogy, Bertrand Russell

suggests that "if you always wore blue spectacles, you could be sure of seeing everything blue" (Russell, *History*, p. 707). Kant's solution to Hume's skepticism could be stated thus: the laws of physics and mathematics describe the spectacles -- consequently they will always hold true.

Empiricism and Apriorism

In attempting to answer the empiricist's threat to the possibility of human knowledge, Kant's philosophy states that the nature of our experience of the world is determined prior to experience. In this way it hopes to demonstrate that all of our experience of nature must, of necessity, conform to laws which are given *a priori*. A position quite removed from that of John Locke. Simply stated these two traditions are as follows: that all experience is fully determined by the active workings of our mind -- the laws of which are given *a priori*; *vis a vis* that the contents of our minds are a passive reflection of the external world, i.e., *a posteriori*. These set the stage for Jean Piaget, who, due to his developmental observations of children, concluded that the human subject is neither the passive mirror of the world, nor does he completely determine the nature of all experience *a priori*, but rather meets the external world half-way, and constructs his knowledge of it out of the interaction between his knowledge and the external world.

Jean Piaget (1896-1980): Genetic Epistemology

Jean Piaget's Genetic Epistemology constitutes an attempt both to determine the ultimate origins of knowledge, and to trace and explain its development from these origins to later levels of knowledge, including scientific knowledge (Piaget, *Principles*, p. 15). Since knowledge, personal or scientific, is not a static affair -- on the contrary it is in a state of continual flux -- the correct path to understanding the nature of knowledge is not through the observation of its manifestation at a particular instant, but rather through the

consideration of its development. He approached this problem by studying the mental development of children.

The Stages of Development and Knowledge Structures

Piaget believed that the child goes through definite stages of development. Each stage constitutes an advance over the previous stages and contains knowledge structures that are new to the stage. The child also possesses knowledge structures of all previous stages, though these may have been modified through the addition of new characteristics (Piaget, *Studies*, p. 6). He distinguished six stages of development: the reflex stage, the stage of first motor habits, the sensori-motor stage, the stage of intuitive intelligence, the stage of concrete intellectual operations, and finally, the stage of abstract intellectual operations. The specific details of each stage are of less interest to us than the process of advancement from one stage to the next.

Piaget held that the individual's knowledge is captured in what he calls knowledge structures. The child *constructs* these through a process of interaction with the environment. The different stages of development are marked off from one another by the level of sophistication of the knowledge structures new to that stage. So, for instance, the sensori-motor stage is characterized by knowledge structures consisting of actions and perceptions. The stage of concrete intellectual operation on the other hand, is characterized by knowledge structures capable of assimilating and performing intellectual operations, which by definition are reversible, on problems of a concrete nature. Learning is a process of extending current structures, or constructing new ones, through a process of modification and combination of pre-existing structures.

Functional Invariants: Assimilation and Accommodation

An important component of Piaget's theory is the existence of functional invariants across all stages of development (Piaget, *Studies*, p. 4). *Assimilation* and *accommodation* constitute a complementary pair of such functional invariants. A child continually assimilates objects to his actions. For example, a child may have learned a pattern of behaviors, i.e., an action schema[2], for opening drawers in a cabinet. Over the course of the child's exploration he will come into contact with new objects, for example a closet door. The child will attempt to apply the action schema for drawers to the closet door -- that is, he will try to open the closet door using the sequence of motor actions he typically employs in opening drawers. In Piaget's terms, the closet door is assimilated to the action schema. Since opening a closet door requires slightly different actions than opening a drawer, the action schema accommodates itself to the closet door, and is modified in the process. Thus, a new object is assimilated to existing action schema, and in the process of the child's interaction with the object, the action schema itself is modified, i.e., it accommodates the object, making the schema more fit for interaction with the object in the future.

The Mental Development of the Child

What follows is a brief summary of the early cognitive development of the child. This will be useful for two reasons. In the first place, it will provide us with a more stable understanding of the idea of *constructing* knowledge through interaction with the environment. In the second, it will help place Piaget's ideas in better relation to those of Locke and Kant, and help underscore the implication of these ideas for education.

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[2] Piaget defines action schemas as "coordinated systems of movements and perceptions, which constitute any elementary behavior capable of being repeated and applied to new situations, e.g., grasping, moving, shaking an object" (Piaget, *Play*, p. 274).

Sensori-Motor Intelligence

The first 18 to 24 months of the life of the child, the pre-linguistic period, consists of three progressive stages. The first is the reflex stage. This is followed by the stage of circular reactions, or habits. Finally the infant reaches the stage of sensori-motor, or practical intelligence. Through use, the initially weak reflexes of the child become strengthened. As each reflex encounters a new object, the object is assimilated to the reflex. This period of assimilation of objects to the reflexes is followed by a period of circular reactions. As the child takes more interest in the consequences of his actions, he repeats them. But each repetition is not merely identical to the preceding one, it is a variation on it, or an *experiment*. This constitutes a more advanced form of assimilation. The pre-linguistic stages of development culminate in the stage of sensori-motor intelligence. "It is an entirely practical intelligence based on the manipulations of objects." It allows for exploration and problem solving in the physical environment (Piaget, *Studies*, p. 11).

The knowledge structures of sensori-motor intelligence are formed primarily through a process of assimilation. In his interactions with the environment, the child is constantly involved in an "organizing activity" (Piaget, *Psychology*, p. 5). Unlike the associationist's view, which holds that over this time the child learns associations between objects that exist in the environment and its own actions, Piaget's view holds that the objects are assimilated to action schema -- that is, *objects are known through the actions performed on them*[3] -- and over the course of this assimilation, the action schemas themselves are modified (accommodation). Thus, the subject actively organizes its experience of objects, which in turn affect this organizing activity. It is a reciprocal relationship -- assimilation of reality to the subject, and accommodation of the subject to reality.

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[3] "At five or six years children still define concepts by starting with the words, 'It is for': a table 'is for writing on,' etc." (Piaget, *Studies*, p. 12).

The Construction of Reality

The child begins life and passes its first 1.5 to 2 years without a sense of self, and consequently experiences the world as an undifferentiated continuum with its body as the (unconscious) center and reference for all events (Piaget, *Principles*, p. 21). During this period of *radical egocentricism*, experience is undifferentiated -- it lacks the categories of object, space, causality and time -- the categories under which the older child orders his experience.

This changes over the course of the second year. Through a process of *reciprocal assimilation*, action schemas become assimilated, one to the other -- in other words, actions become coordinated (Piaget, *Studies*, p. 12). These coordinated actions lead to (coordinated) displacements of objects in the external environment - allowing the child to experience objects in spatio-temporal relation to itself and to one another. Through this interaction, the permanence of objects and the existence of causal relations are recognized and incorporated into the action schemas of the child -- the child begins to experience itself as an active agent which is differentiated from other objects in a physical environment (Piaget, *Principles*, pp. 21-22).

Up until this time the child experiences space across the modalities of sensation, that is, it experiences a visual space, a tactile space, etc. With the coordination of actions, these spaces are experienced in concert and the child acquires a sense of general space. Coordinated actions and the concomitant displacements of objects result in the recognition of object permanence. This, in turn, is also tightly linked to acquisition of a sense of causality and temporal sequence (Piaget, *Studies*, pp. 13-15).

It should be noted that Piaget is not suggesting that the child has a conscious conception of object, causality, space, and time: rather these notions are assimilated to the child's action schemas -- i.e. the child now behaves as one with a sense of causality, object

permanence, etc. The child *constructs* reality by incorporating aspects of it into his actions. It is a sensori-motor conception of the external world. Piaget believed that these action schemas later act as the basis for more abstract representations of these notions. To compare this view to that of John Locke, the child does not passively experience space and time, rather he incorporates spatio-temporal relations into his actions. Against the Kantian view, genetic epistemology holds that the child does not experience objects as they present themselves to the *pre-formed intuitions of space and time* but rather builds spatial-temporal relations into its behavior through a reciprocal process of assimilation of reality to action schemas and accommodation of these schemas to reality.

The Semiotic Function

Over the first two years of life the intelligence of the child is limited to the sensori motor level, i.e., through assimilation of objects to actions, and reciprocal accommodation of these actions to the objects, the child has constructed actions schemas which allow him to solve practical problems. Despite this, the child is not capable of representation (i.e. mental imagery), and all aspects of the problem must exist in the child's sensory field before an action schema may be applied. Towards the end of the second year (Piaget, *Psychology*, p. 51), the semiotic function, the ability to use signs to signify something, begins to make its appearance.

Representation is achieved through a process of imitation. Piaget believed that rather than being a specifically hereditary characteristic, the process of imitation is functionally contiguous with the modes of adaptation characteristic of the sensori-motor stage. Imitation is merely a "primacy of accommodation over assimilation" (Piaget, *Play*, p. 5). For example, imitating a model involves accommodating action schemas to the model (modifying them) so that the action schemas copy or represent the model (semiosis). The model is not assimilated to an action schema, i.e., subsumed as an object well suited for

manipulation by the action schema. Consequently imitation is a primacy of accommodation over assimilation.

By the end of the sensori-motor period the child's skills of imitation reach a level whereby deferred imitation becomes possible -- the child is capable of imitating the model when the model is no longer in the child's perceptual field. This is the beginnings of representation. The actions of the imitation *signify* the actions of the original model. Piaget provides an example (Piaget, *Psychology*, p. 53):

> "But in the case of a little girl of sixteen months who sees a playmate become angry, scream, and stamp her foot (new sights for her) and who, an hour or two after the playmate's departure, imitates the scene, laughing, the deferred imitation constitutes the beginning of representation, and the imitative gesture the beginning of a differentiated signifier."

The semiotic function, which becomes truly representational with the advent of differed imitation, eventually leads to mental representation, or mental imagery. First there is a period of *symbolic play*. Imitative actions performed on objects allow objects to be used as symbols for other objects, or people. The process of symbolic play allows the child to symbolically explore various situations -- as for example, when children play house. Another progression towards mental representation occurs when the child begins to draw (two to two and a half years). Piaget believed that the beginning of the drawing activity was a point halfway between symbolic play and mental representation (Piaget, *Psychology*, p.63). Drawing represents an imitative act, the early goal of which is to produce a graphical copy of real models. Eventually the stage of mental representation, "a kind of interiorized imitation" (Piaget, *Play*, p. 5) is achieved. This constitutes a considerable advance over differed imitation, and symbolic play, in that exploration is possible without the necessity of physical imitation.

Language appears at approximately the same time as the other forms of the semiotic function (Piaget, *Psychology*, p. 84). Individual words are acquired through imitation of phonemes, at first allowing children to utter one word sentences, then two, etc. Grammar appears later. The appearance of language constitutes a tremendous advance for mental representation -- language brings with it an array of signifiers which, besides facilitating representation and allowing thought to extend to remote situation, are shared by the community. This allows for the sharing of experience and validation of ideas by the group.

Conclusion

As we have seen, Piaget believed that an individual's knowledge is captured in knowledge structures, and that these are generated by the individual's activities. This generating activity is a functional invariant, that is, it functions at all stages of development, and it is responsible for the generation and integration of all new knowledge. The functional invariant is a reciprocal process of assimilation and accommodation. New objects, or ideas, are assimilated to existing knowledge structures, and the knowledge structures are accommodated to the new objects. According to Piaget, this principle seems to hold true at all levels of learning.

At the sensori-motor level, the period before language acquisition, knowledge structures consist of action schemas. As new objects are encountered, the child attempts to assimilate the new object to an existing action schema. This is a classification activity. Objects are classified under the particular action schema if they are amenable to assimilation. If not, the child will attempt to assimilate the object to another action schema, or attempt to classify it to a different group of objects. Earlier we remarked that for the child, objects are known through the actions performed on them. If an object can be assimilated to a particular action schema, the action schema is correspondingly accommodated to, or modified by, the object.

Each initial attempt at assimilation represents and experiment. The child attempts to manipulate an object using a particular action schema. The result of the experiment is either a failure to assimilate the object, or assimilation accompanied by accommodation. Even at later stages of development, learning continues as such a process of experimentation. For example, we can consider more abstract levels of problem solving. When a novel idea is encountered, and the individual is required to interact with the idea, there is an initial stage where the individual actively attempts to classify the new idea according to the pre-existing knowledge structures. This is an initial attempt at assimilation. It is an experimental process. If the problem seems amenable to a particular knowledge structure, there will be an attempt at full assimilation, followed by accommodation. If not, a new experiment is begun.

Finally we can briefly consider how these views differ from those of Locke and Kant. Kant's work was primarily an attempt to rescue science from the relative uncertainty of inductive logic. Piaget's researches were deeply influenced by Kant's ideas. Primarily his experiments demonstrated that the intuitions of space and time, and the categories of the understanding, causality for example, were not *a priori* and necessary preconditions for all experience. In fact, Piaget demonstrated that the child constructs these categories of organization, and moreover, the child does so quite late in his development. His views also differ substantially from those of Locke. While Locke believed that the subject passively mirrors the objects of his environment, Piaget thought that objects are known to the subject in terms of the actions (physical, mental) he can successfully perform on them. The subject is active. He constructs his knowledge of an object or idea through a process of experimentation.

This theme is further explored in the following pages. Chapter two represents an attempt to demonstrate that humans naturally approach a novel problem with an initial set of working hypotheses, which may either help a person to a final solution, or hinder him, by leading him into error. Chapter three examines the growth of science as a process of

conjecture and refutation, a view expounded by Karl Popper. The intention is to demonstrate that scientific knowledge and human knowledge both progress after the same fashion of hypothesis generation (attempt at assimilation) and hypothesis testing (accommodation). The final chapter attempts to draw together the main threads of the argument, and based on these principles it suggests a role for the use of computers in education.

CHAPTER TWO

Pre-Scientific Explanations

"[An Old man] came from the South, traveling north, making animals and birds as he passed along. He made the mountains, prairies, timber, and brush first. So he went along, traveling northward, making things as he went, putting rivers here and there, and falls on them, putting red paint here and there in the ground -- fixing up the world as we see it to-day. He made the Milk River (the Teton) and crossed it, and being tired, went up on a hill and lay down to rest. As he lay on his back, stretched out on the ground, with arms extended, he marked himself out with stones -- the shape of his body, head, legs, arms, and everything. There you can see those rocks today."

Introduction

The preceding creation myth of the Blackfeet of Montana (Campbell, *Hero,* pp. 289-290) is just one example of the attempts to answer one of the great questions of mankind -- "How did it all begin?" Mythological answers like this one may serve a number of purposes. One obvious one is that it provides the individual with a working hypothesis, that is, an initial set of assumptions about the nature of the world -- assumptions that allow him to move functionally in his environment.

Humans are limited in both space and time. Consequently the individual must live with an imperfect knowledge of both himself and his environment. It is a hostile environment --

any action or inaction has consequences which may be fatal to the individual. In his book *The Gods of War*, Jordan Peterson notes that:

> "It is the *totality* of human experience, known and unknown, ordered and chaotic, that demands behavioral adaptation. The absence of specific depiction, under inexplicable circumstances, does not alleviate the necessity of appropriate action -- even though the specific nature of that action cannot yet be specified."

In other words, when faced with a relatively novel situation, despite his imperfect knowledge, the individual is still required to act -- to fail to do so would be fatal. However, what actions are appropriate in the face of something never before experienced. Novel situations must be worked through by a process of trial and error. An initial hypothesis must be generated. Without this, action would be impossible. Once generated, this hypothesis may be tested through the application of actions appropriate to it. Such a reaction, hypothesis generation in the face of the unknown, is instinctive, and evolved over the phylogenetic history of man.

When a student approaches a new problem domain, he does not approach it as a blank tablet. He brings with him a set of assumptions which are typically unknown and inaccessible to his instructor. When the student begins to work in the domain, he possesses only a limited knowledge of its nature. Whenever necessary, the student will use his imagination to generate models of the dark and gray aspects of the problem -- aspects for which he has not yet received explicit instruction. This is the natural and necessary reaction, and it is this reaction that prevents the student from merely acting like a sponge, and accepting the instructors 'facts' as they are thrown at him.

The hypotheses generated in the face of the unknown are imaginative -- they are the products of fantasy. While the main themes can be surprisingly common across individuals, the details are private (autistic), and consequently inaccessible to the instructor and other students. Without addressing these tacit assumptions (autistic fantasies) the

instructor may be fighting a loosing battle. Often the instructor must resort to repeating facts until the student learns them either by rote or as patterns. The student can later demonstrate this knowledge through a process of pattern matching -- often leaving the understanding out of the issue completely. Since they are unchallenged at their own level, the initial assumptions are left in place. These assumptions may later become manifest as error when the pattern recognition procedures prove inadequate. Apart from the occasional occurrence of error, these seemingly obdurate assumptions may also function as impediments to further learning.

It is the purpose of this chapter to examine the reality and nature of this instinct to hypothesis generation. A number of pre-scientific domains are considered. The first, the attitudes and beliefs of so-called primitive peoples allow us to consider a realm where hypothesis generation in the face of the unknown is necessary for survival. It is a mode of thought that seems most alien and arbitrary to us, and yet proves functional for the well-being of these peoples. The second, early science, will also prove instructive, particularly that precursor to chemistry: Alchemy. Over the course of the eighteenth and nineteenth centuries the magico-religious father of modern chemistry fell into tremendous disrepute. Alchemy was cursed as an impediment to real science -- a necessary reaction, required for the protection of the empirical methodology, still in the process of finding its roots. Once established, the empirical methodology was itself turned upon the problem of alchemy. From this vantage point it is easier to see alchemy, not only as the precursor of chemistry, but also as a necessary precondition for its genesis. Finally our attention turns towards the children of own era, specifically to their explanations of natural phenomena, as gathered by the eminent psychologist and epistemologist, Jean Piaget.

Primitive Man and his Conception of the World

In his paper *Archaic Man*, Carl Jung discusses his encounters with some primitive tribes in Africa. Over the course of the essay, his position becomes quite clear: archaic man is like modern man, only in some respects -- more so; while in others -- less so. The essential difference between primitive man and modern man, according to Jung, is that the modern has a more differentiated consciousness. In other words, the modern is less likely than the primitive to attribute his emotional state in the presence of an object to the object itself, as an intrinsic property of the object. The modern will tend to recognize his feelings of uneasiness while walking through the woods at night as being a somewhat irrational, even childish, fear. On the other hand the primitive will know, with certainty, that the woods at night are populated by demons and specters. Anyone imagining that modern day western man is over such superstitious nonsense should take a moment to inquire of the older gentleman, accustomed as he is to walking the night time rural byways of the South West of Ireland, on the reality of the Banshee.[4] Jung describes the attribution of phenomena of internal origin (emotional response) to external causes, projection. The difference between primitive man and modern man is the extent to which he projects his own fears and desires on to the objects of his environment.

Issues discussed by Jung in his essay on archaic man which are of immediate concern for us here are those of causality, determinism and chance. Jung provides a hypothetical example (Jung, *Archaic*, p. 56) of a relatively unusual event in the lives of a primitive community. Three women go to the river to fetch water. During the process, one of the women is seized by a crocodile and pulled under. While crocodiles are somewhat timid animals, and do not often attack humans, they have been know to do so on occasion. The questions remaining are these: 'why did the crocodile attack?' and 'why did he choose that particular woman?' An explorer from western Europe would be inclined to simply shrug at

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[4] A Banshee is a female spirit of Gaelic folklore who's scream may be heard in the middle of the night, announcing the upcoming death of a family member.

the matter and weakly mutter: "bad luck, I suppose." The primitive, rigidly adhering to his need for deterministic order in the world, would find such an explanation superficial, and unsatisfactory. He would eventually settle on a deterministic explanation, often one of malicious intent. For example, it may be thought that the medicine man of a neighboring tribe simply used the crocodile as an instrument of murder. The crocodile did not attack the woman by chance, rather he carried out the instructions of the medicine man who wished this particular woman killed. Chance, to the primitive mind, is an absurd superstition of the European explorer.

It is interesting that, despite the entire endeavor of science to causally explain the manifold of nature, the primitive view of the world is more deterministic than the modern one. Chance, however, is not superstitious, as the primitive may suppose. It has been formalized in probability theory, and even forms the basis for quantum mechanics. Despite this, probability theory remains one of the most difficult areas of study for the student. It is notoriously counter intuitive. Take for example the oft-cited Monty Hall problem. There are three doors, behind each of two stands a goat, behind the third awaits a car. The player's goal is to guess which door stands before the car. The player chooses a door. Monty opens one of the other two, reveals a goat, and gives the player the opportunity to change his mind. Is it better for the player to stick to his initial choice, or to choose the other door (that is, the door neither chosen by the player, nor opened by Monty)? The intuitive answer is that the odds of success are the same, regardless of whether the player sticks or switches. The correct answer is that the player should switch: the probability of success if the player switches is twice the probability of success if he sticks to his original choice. Not alone does it take some time to convince someone unfamiliar with the Monty Hall problem that this judgment is correct, the proclamation that it is better to switch may even draw scorn and laughter from people with extensive experience in probability.

After convincing oneself of the veracity of the judgment that switching is the appropriate response, the problem itself appears simple. It is not at all clear why so many should be lead astray by this innocuous problem, which is so completely devoid of complexity. Despite this, the student's intuitions, the tacit assumptions he brings with him, lead him utterly to error.

The difficulty the modern student has with probability theory seems akin to the difficulty the primitive has with the notion of chance events. A few months ago an MIT student, who over the course of six or seven years took a healthy dose of probability theory and mathematics at both undergraduate and graduate levels, dropped his scientific guard and let slip the expression of the primitive: "Probability maybe useful but it is still nonsense. While sitting on a limb of the probability tree, if you take a backwards glance it is clear: there is only one branch and it is weighed with 100% probability all the way down the line." A remark akin to Einstein's "God does not play at dice." The practical utility of probability theory is beyond question. Whether or not it is more superstitious than the pre-empirical conception of magic is a metaphysical question, which like most metaphysical questions, is more likely to become irrelevant than be answered. We are left with this simple conclusion: probability theory remains an area of the utmost difficulty to the student, and this is likely because it goes against the grain of more basic intuitions (instincts, assumptions).

The Ways of Pre-Empirical Medicine

Another phenomenon that will allow us to explore this propensity for hypothesis formation in the face of the unknown is the art of the Shaman of primitive communities. Apart from being the dominating figure in religious life, the Shaman is also "a magician and medicine man; he is believed to cure, like all doctors, and to perform miracles of the fakir type" (Eliade, *Shamanism*, p. 4). In the absence of the possibility of a reasonable biological explanation, the medicine man is required to tend to the needs of his

community. As a substitute, the Shamanistic system is, to our minds, obviously fantastic and even absurd. To the people of his community, he provides an answer and a measure of hope in the face of calamities of unknown origin and destination. He removes the dreadful unknown, and replaces the grotesque face of chance (bad luck) with simple explanations -- explanations which at least allow his people to take some course of action.

The Shaman's healing powers stem from his soul's ability to leave the body, and travel to the spiritual world. In *Shamanism: Archaic Techniques of Ecstasy*, Mircea Eliade describes the medical functions of a north American Shaman (*ibid.*, p. 300):

> "Summoned to a sickbed, the North American Shaman first turns his attention to discovering the cause of the illness. Two principal kinds of disease are distinguished; those due to the introduction of a pathogenic object, and those resulting from 'soul loss.' The treatment of the two cases is essentially different. In the first the effort is directed to expelling the cause of the trouble, in the second to finding and restoring the patient's fugitive soul."

When the cause of the illness is the presence of foreign objects, the Shaman must first divine the cause, and then remove the object by sucking it out of the patient's body. The foreign object may have been inserted by a sorcerer through magical invocation, or placed there by a spirit. The cure is effected during a public ceremony involving the whole community.

Eliade provides the example of the Paviotso Shaman (*ibid.*, p. 302). The ceremony begins with prayers, singing, and dancing on the part of the Shaman. Following this the Shaman goes into a trance, during which his spirit leaves his body. If the nature of the illness is loss of soul, the Shaman seeks the soul of the patient in the land of spirits, and if possible, returns with it. When he comes out of the trance, he immediately relates the details of his journey to the audience. In the case of the presence of a foreign body, the purpose of the trance is to divine the nature and position of the object. When the Shaman returns, he relates what he learned to the audience and removes the object from the patient by sucking

it out through the skin. The Shaman first sucks blood from the patient, and spits it into a hole. After this he continues to suck until he sucks out the magical object (pebble, worm, etc.) which he shows to the audience. This he throws into the hole and covers with dust.

The healing process involves such ceremonies because illness is "regarded as a corruption or alienation of the soul" (*ibid.*, p. 217). The Shaman works on the threshold between the world of the physical and the world of the spiritual. Here he is the protector of the psychic integrity of the community. The Shamans are "pre-eminently the anti-demonic champions; they combat not only demons and disease, but also the black magicians" (*ibid.*, p. 508). The Shaman's experience provides him with knowledge of the nature of death. He is guide to the dead, and his knowledge addresses itself to the horrors that accompany the uncertainties of death.

As a matter of interest, one can briefly question the efficacy of the role of the Shaman. The profusion of the shamanistic art around the globe must indicate, even to our minds, that the Shaman plays a useful role. There are many documented accounts of successful healing rituals, where the stricken patient actually makes a remarkable recovery. The psychotherapeutic effects of the shamanistic ceremony are beyond question. Firstly, the practice of the art is believed to be (and probably is) extremely dangerous to the person of the Shaman. Secondly, the entire community comes out for the ceremony. These two facts must make it abundantly clear to the patient that he is a highly valued member of the community. Thirdly, the Shaman provides an answer, and with this answer (this working hypothesis) the crippling uncertainty, and the anxiety engendered thereby, are removed. The detrimental effects of anxiety are well known. Under prolonged conditions, glucocorticoids are released from the adrenal cortex. These actually hamper the inflammatory processes of the body (which combat damage to its tissues) and reduce the body's resistance to infection (Gray, *Fear and Stress*, p. 62). Given the complete absence

of a more modern system of medicine, the efficacy of the art of the Shaman becomes clearer, and the profusion of Shamanistic practice is perhaps not so surprising after all.

Early European Science: Alchemy

"At the same time I realize 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. [An example is] Empedocles' theory of evolution by trial and error."

- Karl Popper, *Conjectures and Refutations*, (p. 38).

Introduction

Turning our attention to Europe and the renaissance, we alight on another example of pre-scientific thinking. The empirical methodology, which so utterly changed the face of Europe over the course of the eighteenth and nineteenth centuries, was in an initial period of germination. The 'science' of the day consisted in a haphazard collection of folklore, old-wives tales, observations, and superstitions that were more or less obviously such. For our part, we shall examine the precursor of chemistry, or alchemy. The common view of alchemy holds that it was an attempt to transform base metals into gold through chemical and magical means. Many of the great alchemists pursued greater prizes, for example the elusive philosopher's stone -- often understood as a substance capable of facilitating any manner of transformation. Carl Jung believed that for a number of the medieval and renaissance alchemists, their art, or *opus*, was predominantly a psychological affair. In fact, the texts of these natural philosophers of old were of tremendous use to him in both his practice, and the development of his psychological theory. Over the course of its lifetime, with it inception in the first or second millennium BC, and its demise during the seventeenth and eighteenth centuries, alchemy enjoyed a rich and varied history. Since our

only concern with alchemy is to taste briefly of its attempts at scientific explanation, we will limit ourselves in the study of this fascinating area to but a cursory glance.

The Gold

Gold, that ancient symbol of wealth and order, divinity and royalty, derives its intoxicating characteristics from identification with the sun. Every morning the sun rises and dispels the terrors and dangers of the night, returning order and security to the earth. The sun is the prototype of the Hero: every evening he plunges into the sea, and there does battle with the sea monster of the night, only to emerge triumphantly in the morning to light the new day. In ancient Egypt, one cosmology describes Re the solar god as the creator and first King who "put order (ma^{c}at) in the place of Chaos" (Eliade, *History Vol. 1,* p. 91). Re was the father of the first Pharaoh, endowing the succeeding line of Pharaohs with divine origins. Moreover, the Pharaoh as the current king and ruler, is the incarnation of the Sun God on earth. He maintains the balance of ma^{c}at in the kingdom.

The divine and royal nature of the sun, and by association, gold, is also evident in European culture. The Christ, the Son of God, the Savior and Ruler of men, is typically depicted in paintings with a golden halo. This symbol of divinity is the symbolic identification of Christ with the sun. The same holds true for the Crown, the premier symbol of the King. It identifies the king not only with the Sun, and by extension with order, but also links him to the divine, or the divine order. Each coin, round and golden, also representative of the sun, bears the image of the king. It becomes easy to see how gold can come to represent the highest value among material substances.

Jung writes (Jung, *Psychology and Alchemy*, pp. 343-344)

> "A similar idea is to be found in Michael Maier [17th Century Alchemist]: The sun, by its many millions of revolutions, spins the gold into the earth. Little by little the sun has imprinted its image on the earth, and that image is the gold. The sun is the image of God, the heart is the sun's image in man, just as gold is the sun's image in

the earth ... and God is known in the gold. This golden image of God is the *anima aurea*, which when breathed into common quicksilver, changes it into gold."

Early Origins

In *Prelude to Chemistry: An Outline of Alchemy*, John Read suggests that Alchemy probably had its ultimate origins in Egypt, and from there spread to China and Europe. The two main themes of alchemy were both present in ancient Egypt -- the attribution of the highest value to gold, and the pursuit of the incorruptible body. The Egyptians had long been fascinated by the mesmerizing powers of Gold. There is archeological evidence that the Egyptians had expert goldsmiths as early as 3,000 BC, and were well skilled at metallurgy, fabric dyeing and other chemical arts (Read, *Prelude*, pp. 4-6). The art of mummification was also carried out in Egypt. At the time of his death, a man was identified with Osiris, the immortal god of the underworld. Mummification was a literal transformation of the corpse of the dead into an immortal god. It entailed bathing the corpse in *neter*, or sodium hydrate, applying oil, and wrapping it in fabric. In ancient Egyptian, the word '*neter*' literally means 'god' (Franz, *Psyche*, p. 147). Thus the Egyptians were not only concerned with gold, but also with aspects of immortality, both prominent themes in alchemy.

European Alchemy was probably born from the combination of speculative Greek philosophy and magical chemical techniques from Egypt. At the time, Aristotle's theory of physical matter was dominant. This was the doctrine of the four elements: Earth, Water, Air, Fire. These elements were due to different combinations of the four fundamental qualities: Hot, Cold, Dry, Wet. Aristotle believed that all bodies were composed of the four elements (earth, water, air, fire) in different proportions. It was thought that the properties of matter could be altered by altering the proportions of the basic elements (Read, *Prelude*, pp. 9-10). Thus, by altering the mixture of the elements in a base metal, the alchemist believed that he could transmute these metals into gold. This marked the beginning of the alchemical pursuit and the origins of chemistry.

The Work

The belief that precious minerals were engendered and grew in the earth was a common one. For example, it was thought that the diamond was ripe while the crystal was not ripe. The crystal required more time in the oven or womb of the earth before it attained the level of perfection of the diamond. "It is not without interest that these primitive conceptions of the growth of metals were very long in dying out; they withstood centuries of technical experience and rational thought (one has only to recall the mineralogical ideas adaptable to Greek science)" (Eliade, *Forge*, p. 45). The same was thought to be true of gold. The base metals were ripening in the womb of the earth, and if given enough time, they would attain the perfect state of gold. Thus many alchemists believed that the transformation of a baser metal into gold was simply a matter of accelerating and perfecting the process of nature.

The actual work of the alchemist was a mixture of laboratory experimentation and what we would now call mysticism. The process of transformation was thought to take place in four stages, the blackening, the whitening, the yellowing, and the reddening. This was later reduced to three: blackening, whitening and reddening. The blackness, or *nigredo*, was the initial state. It represented the *prima materia*, or "primordial matter, from which all things came and to which all things revert" (Read, *Prelude*, p. 10). The *nigredo* was considered the initial chaos, and thought to be produced by the separation of the elements followed by the union of the opposites as male and female. The death of the product of this union would constitute the *nigredo* (Jung, *Psychology and Alchemy*, p. 230). The whitening could be achieved either through the washing of the *nigredo*, or through the resurrection of the *nigredo* by the reunification of the soul and the body. The final transformation, from the white to the red, was achieved by raising the heat in the furnace. "The red and the white are King and Queen, who may also celebrate their 'chymical wedding' at this stage" (*ibid.*, p. 232)

This is an abstraction of the many different forms of the art of alchemy. The procedures varied vastly, as did the language and symbolism used to describe the procedures and the results obtained. The following passage quoted from Jung's *Psychology and Alchemy* exemplifies the sometimes bizarre nature of the alchemical work (pp. 246-247)

"You shall take seven pieces of metal, of each and every metal as they are named after the planets, and shall stamp on each the character of the planet in the house of the same planet, and every piece shall be as large and as thick as a rose noble. But of Mercury only the fourth part of an ounce by weight and nothing stamped upon it.

Then put them after the order in which they stand in the heavens into a crucible, and make all widows fast in the chamber that it may be quite dark within, then melt them all together in the midst of the chamber and drop in seven drops of the blessed Stone, and forthwith a flame of fire will come out of the crucible and spread itself over the whole chamber (fear no harm), and will light up the whole chamber more brightly than the sun and moon, and over your heads you shall behold the whole firmament as it is in the starry heavens above, and the planets shall hold to their appointed courses as in the sky. Let it cease of itself, in a quarter of an hour everything will be in its own place."

It is unnecessary to go into the details any further. It will suffice to say that these early chemists, in the absence of better information, used mythical and religious conceptions to explore the unknown chemical reactions they generated in their laboratories. Without the aid of a 'more scientific' methodology, they used their fantasy, or imagination, to explore the unknown in matter, to provide them with working hypotheses. Jung writes (Jung, *Psychology and Alchemy*, p. 241)

"To do them justice we must add that all knowledge of the nature of chemistry and its limitations was still completely closed to them, so that they were as much entitled to hope as those who dreamed of flying and whose successors make the dream come true after all. Nor should we underestimate the sense of satisfaction born of the enterprise, the excitement of the adventure, of the *quaerere* (seeking) and the *invenire* (finding). This always lasts as long as the methods employed seem sensible. There was nothing at the time to convince the alchemist of the senselessness of his chemical operations; what is more, he could look back on a long tradition which contained not a few testimonies of such as had achieved the

marvelous result. Finally the matter was not without promise, since a number of useful discoveries did occasionally emerge as byproducts of his labors in the laboratory. As the forerunner of chemistry alchemy had a sufficient *raison d'être*. Hence, even if alchemy had consisted in -- if you like -- an unending series of futile and barren chemical experiments, it would be no more astonishing than the venturesome endeavors of medieval medicine and pharmacology."

The Emergence of Modern Science

Eventually two major trends emerged in European alchemy. One remained concerned with the laboratory experiments, while the other focused more and more on spiritual issues. With the publication of Robert Boyle's *The Skeptical Chymist*, the four element theory of matter was replaced with the modern idea of the element (Read, *Prelude*, p. 31), and the laboratory pursuit of the philosopher's gold was gradually replaced by the more familiar methodology that we now call chemistry. The spiritual side of alchemy developed into hermetic philosophy (Jung, *Psychology*, p. 227). However, this philosophy did not endure long with the emergence of the more rationalistic spirit of the enlightenment. Thus, after a life span of some two thousand years, the practice of alchemy came to a gradual end over the course of the 17th and 18th centuries.

While it may be impossible to determine in any precise way the influence alchemy had on the development of modern science, the fact that the errors of the alchemists were useful cannot be denied. Paracelsus introduced chemistry into medicine, crude as his chemistry may have been at the time; and it was Robert Boyle's alchemical work that lead him to the conclusions which served as the corner stone for the building of chemistry.

Sir Isaac Newton, father of modern science, spent many years studying alchemical texts and running experiments in his laboratory. He believed that the secrets of nature had been imparted to a select few through divine revelation. He thought that this information had subsequently been lost. Only fragments of it remained in mythical form. As such it would remain hidden from the vulgar. The rest could be rediscovered through experimentation

(Eliade, *History Vol. 3*, p. 260). Dobbs believed that Newton never doubted the general validity of alchemy and his career can be seen as an attempt to integrate alchemy and mechanical philosophy (*ibid.*, pp. 260-261). It is interesting that, on the publication of his *Principia* Newton's opponents claimed that his 'forces' were 'occult qualities.' In a way, Dobbs agrees: "Newton's forces were very much like the hidden sympathies and antipathies found in much of the occult literature of the Renaissance period. But Newton had given forces an ontological status equivalent to that of matter and motion. By so doing, and by quantifying the forces, he enabled the mechanical philosophies to rise above the level of imaginary impact mechanisms" (Dobbs, quoted in *ibid.*, p. 261). Considering Newton's work on forces, Richard Westfall concluded that modern science is the result of the wedding of hermetic philosophy and the mechanical philosophy (*ibid.*).

Paracelsus: Physician, Scientist, Mystic

Theophrastus Paracelsus is thought to have been one of the first men to incorporate the ways of chemistry into medicine. It may be instructive to briefly consider his medical system. With its mixture of mysticism and chemistry, it may even constitute a midpoint in the progression of medical science from the Shaman to modern medicine. Paracelsus was born at Einsiedeln Switzerland in November 1493. By 1525 his reputation as a physician earned him an invitation to the university at Basal, but his scorn for his colleagues and the academic medicine of the day soon drove him to resume his travels about Europe and Russia. It was on his constant wanderings that he derived his vast experience. Jung describes him as "a pragmatist and empiricist without parallel (Jung, *Paracelsus*, p. 11). As an alchemist, Paracelsus was thoroughly materialistic. For him "the spiritual principle takes second place, this being the *anima mundi* that proceeds from matter" (*ibid.*, p. 9). Though he was an animist, projecting anthropomorphic spirits into matter, his materialistic outlook (that matter is primary) helped pave the way for the development of the empirical methodology, still some centuries in the future. Consequently, as well as being a pioneer in

the medicine of his day, his work contributed to the founding of natural science, and modern chemistry.

In *The Book Paragranum*, Paracelsus sets forth the physicians work (Jung, *Paracelsus The Physician*, p. 18). The physician must look outside the patient for the clues to the patient's ailment. "Only external things give knowledge of the internal; without them no internal things may be known" (Paracelsus, quoted from *ibid.*, p. 18). The physician must be an alchemist. He must know the ailments of the elements as these correspond to those of man. He must also be familiar with the transformations of alchemy -- he must understand the alchemy (digestive transformation) of the stomach (*ibid.*, p. 19). The physician must also be an astrologer. The microcosm (body) is inextricably bound up with the macrocosm (heavens) -- without knowledge of the heavens the physician remains incapable of understanding the body (*ibid.*, p. 20). Paracelsus was also a firm believer in the powers of magic, and was known to employ amulets and seals in his practice. Finally, Paracelsus practiced the ancient art of charming an illness, which was also practiced in ancient Egypt. His method, the *Theorica*, was a religious cure, whereby the physician spoke to the patient as though with the grandiose words of God. Jung believed that a fair portion of Paracelsus' success could perhaps be attributed to this intuitively devised, psychotherapeutic method (*ibid.*, pp. 28-29).

Alchemy: Conclusion

The alchemist drew from astrology, religion, mysticism, and whatever else offered itself as a useful analogy, and used these to help him explore unknown worlds. Using such tools as were available, he built hypotheses about the hidden laws of nature, and explored the consequences of these hypotheses. These hypotheses were the products of his imagination -- and despite their sometimes bizarre form, were inevitable, and formed the necessary course of early science. As we turn our attention to Piaget's study of the early pre-

scientific explanations of modern children, we see similar patterns in the types of hypotheses they generate.

Pre-Scientific Explanation in Childhood

Animism

In *The Child's Conception of the World*, using the method of clinical interview, Piaget attempts to specify and examine the child's pre-scientific view of the world. Rather than using ideas of mechanical causality, the child finds explanation for many classes of phenomena by endowing the objects in his environment with life and consciousness. This he called *animism*. The word animism was initially used by anthropologists to describe the manner in which primitive peoples endow nature with souls and living spirits. Piaget uses the term in the same sense with children. Animism is the propensity of children to endow objects with consciousness and life, to animate the objects in their environment.

Piaget noticed four stages of animism. For children in the first stage, all objects may be conscious. For children of the second stage, only objects that move are conscious. For children of the third stage, all objects that move of themselves are conscious. This excludes objects that are obviously moved by external agents. In the fourth and final stage, children attribute consciousness only to animals.

As an illustration of the first stage, Piaget provides the following examples. These were taken from two interviews with a child, the first at age eight and a half and the second at age nine and a half. The first interview went as follows (*ibid.*, pp. 174-175):

Vel (8.5) says that only animals could feel a prick, thus showing he is able to differentiate in this answers. What he means, as a matter of fact, is that only animals can feel pain. Clouds, for example, should not feel a prick. "Why not? -- *Because they are only air.* -- Can they feel the wind or not? -- *Yes, it drives them.* -- Can they feel heat? -- *Yes.*" But as far as mere consciousness is concerned, any object may be conscious at times; "Can the bench feel anything?

-- No. -- If someone burnt it, would it feel that? -- Yes -- Why? -- Because it would get smaller. --
Does a wall feel anything? *-- No.* -- Would it feel it if it was knocked down? -- *Yes.* -- Why? --
Because that would break it" A moment later: "If I pull off this button (a coat button), will it feel
it? -- *Yes.* -- Why? -- *Because the thread would break.* -- Would that hurt it? -- *No, but it would
feel that it was tearing it."* "Does the moon know it moves or not? -- *Yes.* -- Does the bench know
it is here? -- Yes. -- You really thinks so? Are you sure or not sure? -- *Not sure.* -- What makes
you think perhaps it doesn't know? -- *because it is made of wood.* -- And what makes you think it
may know? -- *Because it is here."* "When the wind blows against the Saleve, does it feel there is
a mountain there or not? -- *Yes.* -- Why? -- *Because it goes over it."* "Does a bicycle knows it
goes? -- *Yes.* -- Why? -- *Because it goes.* -- Does it know when it is made to stop? -- *Yes.* -- What
does it know with? -- *The pedals.* -- Why? -- *Because they stop going.* -- You think so really? --
Yes (we laugh). -- And do you think I think so? -- *No.* -- But you think so? Can the sun see us? --
Yes. -- What does it see us with? -- *With its rays.* -- Has it got eyes? -- *I don't know.*

The same subject at nine and a half years (*ibid.*, pp. 175-176):

We hung a metal box from a double string and placed it in front of Vel, in such a way that, on
letting go of the box, the string unwound making the box turn round and round. "Why does it
turn? -- *Because the string is twisted.* -- Why does the string turn too? -- *Because it wants to
unwind itself.* -- Why? -- *Because it wants to be unwound* (= it wants to resume its original
position, in which the string was unwound). -- Does the string know it is twisted? -- *Yes.* -- Why?
-- *Because it wants to untwist itself, it knows it's twisted!* -- Does it really know it is twisted? --
Yes. I am not sure. -- How do you think it knows? -- *Because it feels it is all twisted."*

During the second stage, consciousness becomes restricted to objects that move. Of this,

Piaget gives a number of examples (*ibid.*, p. 180):

Kae (age 11) spontaneously unites consciousness with movement: "Does the sun know anything?
-- *Yes, it heats.* -- Does it know that it's hidden from us in the evening? -- *Yes, because it sees the
clouds in front of it ... no, it doesn't know, because it isn't it that hides. It's the clouds that go in
front of it."* Thus, if the sun hid itself, it would know, but since it is hidden without having done
anything itself, it doesn't know. "Does a bicycle know when it goes? -- *Yes it feels the ground."*
"Does a motor know when it goes? -- *Yes, it feels it isn't still in the same place."*

Pug (age 7 yrs. 2 mths.): "Does the sun know when it sets? -- *Yes.* -- Does it know it gives light? -
- *No.* -- Why not? -- *Because it hasn't any eyes, it can't feel it."* "Does a bicycle know anything?
-- *No.* -- Why not? -- *I mean it knows when it goes fast and when it goes slowly.* -- Why do you
think it knows? -- *I don't know, but I think it knows.* -- Does a motor know when it's going? --
Yes. -- Is it alive? -- *No, but it knows.* -- Is it the driver who knows or the motor? -- *The driver.* --
And the motor? -- *It knows too."* Benches, tables, stones, walks, etc., neither feel nor know
anything.

At the third stage the child denies consciousness of anything which does not move by

itself, for example (*ibid.*, pp. 182-183):

Ross (age 9 yrs. 9 mths.) started by ascribing consciousness to animals but refusing it to the table: "Would a table feel it if I were to prick it? -- *No*. -- Why not? -- *Because it is not a person*. -- Can the fire feel anything? -- *No*. -- If someone threw water on it, would it feel that? -- *No*. -- Why not? -- *Because it is not a person*. -- Does the wind feel anything when the sun is not shining? -- *Yes*. -- Doesn't it know it is blowing? -- *Yes*. -- Does the sun feel anything? -- *Yes*. -- What does it feel? -- *It feels it's heating, etc*." Ross likewise attributes consciousness to the stars, the moon, the rain and streams, but refuses it to bicycles, motors and boats. "Are you sure of all this or not very? -- *Not very*. -- Have you thought about it before? -- *No*. -- Why aren't you very sure? -- *I haven't learned it*. -- You say the wind feels something, but you aren't quite sure. Tell me what you think, what makes you think that perhaps the wind doesn't feel when it is blowing? -- *Because it is not a person*. -- And why do you think perhaps it does feel? -- *Because it is it (!) that blows*" "The lake knows its name? -- *Yes, because it moves*. -- It knows it moves? -- *Yes, because it's it that moves*."

Finally, at the fourth stage, consciousness is attributed only to animals and maybe plants. Not surprisingly, the belief that the sun and moon are alive is not so easily shaken, as it is for clouds, for example, or bicycles. Any knowledge of the history of religious ideas would have led us to suspect nothing less. A couple of examples will suffice (*ibid.*, p. 186):

Pig (age 9) denies consciousness to the clouds, to fire and to a flower "*because it isn't alive*." But the sun is able to feel: "Why? -- *Because it is alive*." The stars cannot feel "*Because they are just sparks*." -- And isn't the sun a spark? -- *No, it's a light*." The moon also is conscious, but not the clouds, because they are "*made of smoke*" and smoke "*can't move*". "Can the clouds move by themselves? -- *No*. -- And the moon? -- *Yes*." Fire can't feel anything "*because you have to make it*," neither can a stream because "*it's the air that makes it move*."

Gol (age 6, very advanced) restricts consciousness to animals and the moon "*because, at night, it always goes to the same place*." Fire, on the other hand, is not so conscious "*because it always stays in the same place*," neither are clouds because "*the wind drives them*"

Artificialism

Another aspect of childhood explanation is what Piaget termed *artificialism*. This he defines as the tendency to assume that objects are products of human creation, rather than attributing their existence to some manner of material causality. At a later stage, creation is attributed to more natural causes. A few examples will suffice.

Gaud (age 6 yrs. 8 mths.) "What is the moon like? -- *Round. Sometimes there is only half of it*. -- Why is there only half of it? -- *Because that is how it starts*. -- Why? -- *Because there is a lot of*

daylight (he means that the moon remains small during the day and only grows at night). -- Where is the other half? -- *That's because it is not finished.* -- What does it make itself like? -- *Round.* -- How does it begin? -- *Quite small; then it keeps on getting bigger.* -- Where does it come from? -- *From Heaven.* -- How does it make itself? - *Quite tiny.* -- Does it make itself all alone? -- *No, God does it.* -- How? -- *With his hands.*" Gaud adds that the moon is alive and conscious. It deliberately follows us about, etc. The sun is equally alive and has been made.

Caud (age 9 yrs. 4 mths.) "How did the sun start? -- *With heat.* -- What heat? -- *From the fire.* -- Where is the fire? -- *In Heaven.* -- How did it start? -- *God lit it with wood and coal.* -- Where did he get the wood and coal? -- *He made it.* -- How did the fire make the sun? -- *The fire is the sun.*" Up to now it seems that Caud is no longer animistic but this is not so: "Does the sun see us? -- *No.* -- Does it feel the heat? -- *Yes.* -- Does it see at night? -- *No.* -- Does it see in the day? -- *Yes, of course! it sees because it makes the light for itself.*"

After a transmission period, the origins are attributed to natural causes (*ibid.*, pp. 273-277):

Font (age 6 yrs. 9 mths.) says that the sun is conscious, it is made of fire and it comes "*from the mountain.* -- Where from? -- *From the mines.* -- What is it? -- *People go looking for coal in the ground.*" As to the moon: "*It was made by the sun.* -- How? -- *With the fire from the mountain.* -- Where does the moon come from? -- *From the mountain.* -- What was there in the mountain? -- *The sun.* -- Where does the sun come from? -- *From the mountain.* -- How did it begin? -- *With fire.* -- And how did this fire begin? -- *With matches.* -- And how did the mountain begin -- *With the earth ... it was people who made it.*"

Chal (age 9 yrs. 5 mths.): "How did the sun begin? -- (Thoughtfully) *First it was small, then it got big.* -- Where did this little sun come from? -- *If must have been made by the clouds.* --What is the sun made of? -- *Of air.*" As to the clouds they also come from the air.

Aud (age 9 yrs. 8 mths.) "What is the sun made of? -- *Of clouds.* -- How did the sun begin? -- *To begin with, it was a ball and then it caught fire.*" The clouds from which the sun was born also came from the sky, the sun is, therefore, "*a cloud from the sky.*"

Ant (age 8.5 yrs.): "How did the moon begin? -- *The stars ran into each other, and that made the moon.* -- And where do the stars come from? -- *They are flames which have always been there from the beginning.*"

The Child: **Tabula Rasa** *or Active Hypothesis Generator*

As is evident from the explanations offered, the child has not yet received a causal explanation of the origin of the moon and the stars. Yet he is not a blank tablet awaiting the scribblings of the astronomer or physicist. He has a number of working hypotheses,

which he uses in the absence of better explanations. The question of the value of these hypotheses is a separate one from that of their existence. The belief that the child is a passive recipient of information, and does not play a very active role in constructing his conception of the environment is surely untenable in the face of this evidence. In his book, Piaget provided a great number of examples. The existence of common themes in the children's explanations is almost as surprising as it is interesting.

Conclusions

Examples drawn from the areas of anthropology, history of science, and child psychology provide overwhelming evidence that humans have a strong propensity to generate hypotheses in the face of the unknown. It is also evident that these initial explanations are mythical in structure. What are the consequences of this for education?

There are at least two obvious ones. Firstly, when receiving instruction on a new topic, the student may possess any number of ideas that he may bring to bear on the new topic. These may have been collected by the student while exploring other problem domains, or may have been hypothesized in the early stages of instruction. They may be more or less rational or irrational, and may either help the student by leading him to an improved formulation of ideas, or hinder him by misleading him. If these ideas are not addressed, their effect will be left to chance. So the first consequence for education is that, in order to assimilate new information, pre-existing ideas should be explicitly challenged by the new circumstances. This will help to remove the element of chance.

The conclusions we have reached so far indicate that the subject constructs all new knowledge. The second consequence for education therefore pertains to the way we approach learning. The question, simply put, is this: should we continue to teach by providing a top down presentation of material, and hope that portions of this will be

assimilated over the course of continual repetition; or should we engage and employ the human's powerful faculty for hypothesis generation. I think that the answer is obvious. The following chapter, a study of the ways of science, is intended both to reinforce this position, and to explore the possibility of formalizing this approach to learning. The thesis, expounded more clearly in the final chapter, is this: in some domains, the reciprocal process of teaching and learning could be replaced by active exploration and experimentation.

CHAPTER THREE

The Scientific Pursuit

"While I wanted to think everything false, it must necessarily be that I who thought was something; and remarking that this truth, *I think, therefore I am*, was so solid and so certain that all the most extravagant suppositions of the skeptics were incapable of upsetting it, I judged that I could receive it without scruple as the first principle of the philosophy that I sought."

- Rene Descartes (quoted from Russell, *History*, p. 564).

"When I analyze the process that is expressed in the sentence, "I think," I find a whole series of daring assertions that would be difficult, perhaps impossible to prove ... In place of the "immediate certainty" in which the people may believe in the case at hand, the philosopher thus finds a series of metaphysical questions presented to him, truly searching questions for the intellect; to wit: "From where do I get the concept of thinking? Why do I believe in cause and effect? What gives me the right to speak of an ego, and even of an ego as a cause, and finally of an ego as the cause of thought?" Whoever ventures to answer these metaphysical questions at once by an appeal to a sort of *intuitive* perception, like the person who says, "I think, and know that this, at least, is true, actual, and certain" -- will encounter a smile and two questions marks from a philosopher nowadays. "Sir," the philosopher will perhaps give him to understand, "it is improbable that you are not mistaken; but why insist on the truth?" --"

- Friedrich Nietzsche, *Beyond Good and Evil* (pp. 24-25).

The Meaning of Truth

We now turn briefly to an old and well-trodden topic in philosophy -- that is, the meaning of truth, and our ability to capture and hold it. Our interest here is not metaphysical, but rather, practical. Out of the many different ways of looking at the universe, and the many different conceptions of the meaning of the words "truth" and "certainty," we wish to answer a simple question: "What shall we tell our students?" In other words, what are the educational consequences of holding a particular metaphysical conception of the certainty and stability of our knowledge of the world. By "educational consequences" we mean, what effect such a conception will have on the training, and consequent research activities, of our young scientists.

The early epistemological optimism of Bacon and Descartes was built on the idea that truth was manifest (Popper, *Conjectures*, p. 5). Though it may be obscured, a little care on the part of the observer could remove this obscurity, allowing for *immediate* and *certain* recognition of the truth. Descartes believed that all things that are conceived very clearly and distinctly *are true*. Thus, we are entitled to apodictic knowledge of mathematics and physics, so long as we did not rely upon our senses, which may in fact lead us into error. The mind, employing the light of reason, allows us apodictic knowledge of the true nature of things. For Descartes, this is due to the existence of God. Since God exists and is good, if we distinctly perceive something as true, we will not be deceived. Thus the laws of mathematics and physics must be true, and certain -- else we should not perceive them as such (Russell, *History*, pp. 564-568).

Locke, on the other hand, insisted that all human knowledge is ultimately derived from sense-perception -- that is from experience of the external world. This theme was picked up by Berkeley who proffered the argument that matter does not have an existence apart from perception of it. That matter may continue to exist is due to its being constantly perceived by God (Russell, *History*, p. 647). Hume pushed the view to its logical

conclusion, and suggested that we do not even possess firm grounds for belief in the existence of the external world. He himself thought that such a conclusion was perhaps no more than an idle curiosity. Despite this, two of his arguments were of profound importance, and had a corresponding effect on science and philosophy. The first of these is against the assumption, fundamental to science, that every event is anticipated by its cause, and moreover, that there is a necessary connection between these two events (cause and effect). Hume stated plainly that while we may consistently witness the conjunction of two types of events, we have no perceptual access to a necessary connection. Thus we have no right to speak of causal relationships as real and necessary. The second, his argument against the certainty of induction, seems to this day to be conclusive. That we have observed regularities in the past is not grounds enough to guarantee that that regularity will persist in the future. The net result of these inquiries was the conclusion that, while nature may *appear* to correspond to so-called laws, there are no grounds for assuming that she actually does, or that she will continue to do so. In other words, nature does not necessarily conform to the laws that science may set for her, and we are forever denied exact knowledge of her inner workings.

Kant's *Critique of Pure Reason* specifically addressed the issue of endowing science with apodictic certainty. According to Kant, nature as a thing in itself, is inaccessible to us. We only have access to our experience of nature. This much he would cede to Hume. It was also this idea that helped him to circumvent the problems raised by Hume. According to Kant, the apparatus with which we experience nature orders our experience according to the intuitions (*anschauung*) of time and space, and subsumes all judgments of experience under the categories of the understanding. The propositions of mathematics and physics describe the apparatus of experience, not nature as a thing-in-itself. Since this apparatus is given independent of experience, or *a priori*, these propositions escape the uncertainty associated with inductive knowledge.

Kant's solution, while certainly daring, feels more like a trick than a real answer. As we are well aware, nature effectively resists our attempts to impose our laws upon her. Kant's answer was an attempt to find a permanent place in our knowledge for Euclidean geometry and Newtonian mechanics. We now know that there are other useful geometries beside Euclidean. Newtonian mechanics works well enough for a midrange of events, but it was far from the final answer in physics. Quantum theory currently rules the very small, while relativity theory rules the very large. Kant's theory was an attempt to demonstrate that Newtonian mechanics must always hold true. But it does not. The only way to save the transcendental philosophy from this refutation is through an *ad hoc* modification. What would this modified theory look like? Perhaps it would continue to insist that we may only experience nature through our intuitions, and our intuitions order experience depending on whether we witness the very large or the very small -- perhaps it would recommend an intuition which changes its *a priori* rules *a posteriori*. An apparent contradiction. Kant's proposition, that we may know nature with certainty *a priori* because the workings of our intuitions are given independent of experience, does not seem to have provided us with final certainty. Where then does that leave us?

Should we strive after an absolute truth or settle for a more relativistic view? In a lecture entitled *Pragmatism's Conception of Truth*, delivered at the Lowell institute in Boston in 1906, William James set forth his own interpretation of the word 'truth.' In a somewhat characteristic fashion, James sets forth the pragmatist's position: given that an idea is true, what difference will it make in concrete terms. "What, in short, is the truth's cash-value in experimental terms?" "True ideas," he says, "are those that we can assimilate, validate, corroborate and verify. False ideas are those that we cannot" (James, *Pragmatism*, p. 97) He considers verification and validation in practical terms. The process of verifying a proposition consists in acting as though it were true. The sequence of actions thus instigated may be compared to reality. If this comparison results in the perception of a

harmonious progression of agreement, our original proposition may be considered to be true.

The agreement to reality is three-fold. It requires agreement with the concrete and abstract facts, and connections perceived intuitively between these, as well as agreement with the body of truths already possessed by the individual. Thus the pragmatist's conception of truth is as follows: A proposition is true if its consequences are in harmonious agreement with the facts, and the current body of knowledge (James, *Pragmatism*, p. 102). And what of ultimate truth? "The 'absolutely' true," says James, "is that ideal vanishing-point towards which we imagine that all our temporary truths will someday converge."

This view is indeed attractive. It disposes of much metaphysical claptrap by giving an operational definition to truth. There is one obvious objection to such a view. If, as the pragmatist suggests, something is true in as much as it promotes our categorical well being, how can we determine truth independent of ethical considerations. Such a conception of truth would result in a reversion to a world view that predates the hard-won scientific outlook we inherited from the Europeans of the Seventeenth and Eighteenth centuries. "What is?" and "What should be?" would once again be confused, and the inner workings of science would once again be subservient to ethical considerations.

This view of truth also allows things to be true only in so far as they agree with what we see, and what we believe to be possible. There are a number of difficulties with such a position. Firstly, observation is only possible in the light of a theory. Karl Popper provided a simple demonstration of this at a lecture in Vienna (Popper, *Conjectures*, p. 46). He gave his audience the following task: to spend a few minutes observing, and write down everything they observed. His students were understandably baffled and inquired what it is that they should observe. We cannot simply observe -- the manifold of experience is by far too chaotic to allow for meaningful observation without the ordering effect of a leading idea. We may however search for something. This may be confirmation of an expected

result, or detection of a result which was not expected. But all searching is guided by the expected result. Sometimes it is necessary to step outside the theory currently held to be true and adapt a new one simply to become aware of problems. In *Against Method*, Paul Feyerabend provides an excellent description of such strategies, and we shall have occasion to return to these later.

When such an instrumental definition of truth is in effect, it hampers the progress of scientific research. A theory that is held to be true because of its utility may not allow for the latitude that is sometimes required for the unearthing of counter-evidence. Bertrand Russell argued that such an instrumental view of truth must inevitably lead to authoritarian and totalitarian situations (Popper, *Conjectures*, pp. 4-5). Karl Popper is inclined to agree. But what alternatives do these two suggest. Speaking of the scientific philosopher, Russell (*Our Knowledge of the External World*, pp. 240-241) recognizes the difficulty of maintaining the belief in an objective truth and the possibility that the researcher may attain to such truth. Faced with continual error, it is easily understood how the researcher may succumb to an instrumental conception of truth. Russell believes that maintaining the ideal of an objective truth, and pursuing that ideal, is the one of the highest, and most difficult of virtues for the researcher. Popper suggests a position of critical rationality. For Popper, there is objective truth, and moreover it is above human authority. However, Hume's conclusion that we are unable to know nature with certainty is unavoidable. Therefore we must recognize our knowledge as conjectural, and use our critical judgment to reject obviously false conjectures whenever possible. For Popper, it is impossible for us to know nature with certainty. Our task is to successively approximate objective truth through a continual process of elimination of error.

T. S. Kuhn: Paradigms of Science

"We habitually act upon hypotheses, but not precisely as we act upon what we consider certainties; for when we act upon a hypothesis we keep our eyes open for fresh evidence."

- Bertrand Russell, *A History of Western Philosophy*, (p. 815).

In his study *The Structure of Scientific Revolutions* Thomas Kuhn outlines the characteristics of what he calls normal science, and science in a state of crisis. He describes paradigms as new ideas that are sufficiently novel as to attract adherents away from competing ideas, and still contain a number of conundrums which new practitioners may work at solving. Once a new paradigm is in place, normal science busies itself with settling the details of the new paradigm. Some of the tasks undertaken are: determining the details of the paradigm with greater precision; resolving some of the remaining ambiguities; and attempting to resolve novel problems, perhaps even from other domains, using the tools of the new paradigm.

He also describes science in a state of crisis. This occurs during the transition period between different paradigms. By filtering through the history of science, Kuhn noticed that as the scientific endeavor continues under the rubric of a current paradigm, data are gathered which can not be explained by the paradigm. Kuhn calls these data anomalies. When an anomaly is uncovered the typical reactions are to 1) ignore the result, 2) assume it is an error, 3) perform an *ad hoc* modification of the paradigm, or 4) set it aside as a conundrum. As science advances under a particular paradigm, experimental and measuring techniques become more sophisticated. Over time, the number of anomalies multiplies. The weight of the anomalies eventually causes a scientific revolution -- that is a switch to a new paradigm, and the process begins anew. Kuhn states (Kuhn, *Structure*, p. 77): "the decision to reject one paradigm is always simultaneously the decision to accept another,

and the judgment leading to that decision involves the comparison of both paradigms with nature *and* with each other."

It is interesting that the new paradigm which emerges from the scientific revolution has often been anticipated, in a more or less complete form, sometimes long before the emergence of the crisis. These anticipations are usually ignored, since they are out-shone by the explanatory power of the current paradigm. Kuhn cites one example (Kuhn, *Structure*, p. 75):

> "The only complete anticipation is also the most famous, that of Copernicus by Aristarchus in the third century BC. It is often said that if Greek science had been less deductive and less ridden by dogma, heliocentric astronomy might have begun its development eighteen centuries earlier than it did."

Kuhn notes that this view ignores the problem in its historical context, and fails to account for the explanatory power of Ptolemaic astronomy. Yet the possibilities must give us pause. Soon we shall consider the value of working within the current paradigm, and the advantage of being able to step outside it.

Karl Popper: Conjectures and Refutations

Before addressing the issue of stepping outside the prevailing paradigm, we turn our attention to Karl Popper's theory of scientific discovery. In his book *Conjectures and Refutations* he describes his ideas as originating from two sources. The first was his concern over the issue of scientific demarcation. The question for which he sought an answer was: *When is a theory a scientific theory?* He placed the problem in a historical context, and for the sake of exposition it may benefit us to do the same. His immediate difficulty concerned two new theories at the turn of the century -- these were Einstein's theory of relativity and Freud's theory of psychoanalysis (Popper, *Conjectures*, p. 34). Both theories laid claim to being scientific theories, yet he felt that Einstein's theory was

of a different character than Freud's. In trying to resolve this difficulty, he came to the conclusion that *a theory is only scientific in so far as it may be refuted* (*ibid.*, p. 37).

He considered the aforementioned theories in the light of this so-called *criterion for demarcation*. Primarily he considered the difference between a perspective bent on verification and one inclined towards refutation. It is not difficult, says Popper, to gather data that verify a theory. Astrology provides an obvious example of this. All good tests of a theory consist in an attempt to refute it. A verification may be useful, but only in so far as it is a verification of a risky prediction, that is, a prediction upon which the theory differs from reasonable competing theories. He cites Eddington's result of 1919 as a successful, and useful attempt at failing to refute relativity. Psychoanalysis, on the other hand, is not capable of refutation, since all possible results can be explained from within the theoretical framework (*ibid.*, p. 35).

This was his problem of scientific demarcation, and its solution. The second source of his theory of scientific progress has its origins in Hume's *Treatise on Human Nature*. Popper found Hume's demonstration that scientific induction lacks logical certainty conclusive. It was with Hume's psychological explanation for the belief in induction that Popper took issue. Hume believed that we are accustomed, by habit, to seeing regularities in experience. Since we have a history of observing the constant conjunction of two events (called *cause* and *effect*), we are in the habit of seeking a 'cause' for every 'effect' observed. But, for a situation to qualify as a repetition, similarities across situations must be recognized. The manifold of experience is too chaotic for similarities to simply be detected. All the failed attempts of artificial intelligence theorists to procure pattern matching programs bear witness to this difficulty. Popper rightly argues that it is impossible for similarities to simply be recognized as obviously such -- they must be actively sought in experience. This is similar to asking a room full of people to observe.

"Observe what?," they will immediately demand. The subject actively seeks regularities in experience. Popper states (*ibid.*, p. 46):

> "Without waiting, passively, for repetitions to impress or impose regularities upon us, we actively try to impose regularities upon the world. We try to discover similarities in it, and to interpret it in terms of laws invented by us. Without waiting for premises we jump to conclusions. These may have to be discarded later, should observation show that they are wrong. This was a theory of trial and error -- of *conjectures and refutations*."

The Logic of Scientific Discovery

It is clear then, observation without a theoretical framework, a leading hypothesis, is impossible. We impose our expectations on the world, and order the data of our experience according to these expectations. The clinical psychologist, George Kelly, outlined a theory of mental disturbances based on such an idea (Rychlak, *Personality*, pp. 708-748). When an individual has a framework of expectations that is maladjusted, he may continue to force all interpretations of experience into such a framework of expectancy. Kelly's method of treatment was to attempt to directly modify his patient's expectancy framework. Popper describes two attitudes, the dogmatic attitude, and the critical attitude. These two attitudes are similar in their willingness to adapt a new framework of expectancy or hypothesis, but differ in their willingness to let it go (Popper, *Conjectures*, p. 49). An individual with a dogmatic outlook will tend to try to massage the facts until they fit into the framework of his leading idea. Facts that do not fit may be ignored, or their existence may even be denied. Such an attitude is destined for a maladjusted end.

As an alternative to this, Popper advocates a critical attitude. A researcher will use a theory and capitalize on its explanatory power. He should neither be too quick, nor too slow to abandon the theory. Some theories are difficult, and can only be developed through a process of successive approximations. To give up on a theory too quickly can

obviously be a terrible mistake. Despite this, a critical researcher will always be on the lookout for data which refute his working hypothesis. As John Eccles said (Popper, *Conjectures*, p. 3), "I can now rejoice even in the falsification of a cherished theory, because even this is a scientific success."

Thus Popper's logic of scientific discovery is as follows. Science progresses through a process of hypothesis generation and hypothesis testing. In order for a hypothesis to be scientific, in the strictest sense, it should be testable -- that is, it should be falsifiable. The attitude of the researcher to the hypothesis should be critical. He should take care not to give up on a fledgling hypothesis too quickly. One that shows initial promise, despite some discouraging results, may eventually lead to a better theory -- a theory that is a closer approximation to the truth. This attitude should only be held towards a theory which is obviously in its early stages of development. More generally, the researcher should actively try to refute the current theory. A theory's value can be measured in terms of the number of genuine attempts at refutation it has withstood. Such an approach is necessary. Unless we are to admit that science has become static, that it is no longer in a state of flux and there remains nothing to be explained. Science may only progress by considering each theory as a step, a useful error, along the road to truth. This is the critical attitude. An attitude that does not claim to lay hold of the naked truth, but runs on before itself in its eagerness to eliminate error.

The Ways of Counter Induction

To round out this discussion of the scientific method, I would like to consider an issue raised by Paul Feyerabend in his book *Against Method*. Here he advocates the use of what he calls counter induction. First, he argues, all observation presupposes a theoretical background -- a framework of expectancy. And second, all observation must necessarily be a function of the framework under which it is made. Sometimes it may be useful, even

necessary, to adapt a theory which either a) disagrees with the current paradigm (in Kuhn's sense), b) disagrees with the facts, or c) disagrees with both. This he calls counter induction -- an idea that is not so absurd as it may initially seem.

The method of counter induction can be justified through two considerations. First: all observations are a function of the leading theory. It may be necessary to step outside the current paradigm (whose explanatory power may be tremendous), and adapt a newly conjectured theory. This may be required simply to unearth the very observations necessary to correct, or refute, the leading paradigm. Second: Since data is gathered in the light of a theory, a newly hypothesized theory could easily disagree with established facts, without this being any reflection upon the new theory. All this suggests *prima facie* is that facts gathered under a current theory do not conform to the expectations of a new theory. This says nothing of the facts which may be gathered under the new theory.

Feyerabend illustrates his point with the example of Galileo. It is Galileo's attempt to convince his contemporaries of the correctness of the Copernican cosmology. His point of attack is the so-called tower argument that the Aristotelians used to support the thesis that the earth is stationary. In his *Dialogue* Galileo states (quoted from Feyerabend, *Against Method*, p. 55):

> "Heavy bodies ... falling down from on high, go by a straight and vertical line to the surface of the earth. This is considered an irrefutable argument for the earth being motionless. For, if it made the diurnal rotation, a tower from whose top a rock was let fall, being carried by the whirling of the earth, would travel many hundreds of yards to the east in the time the rock would consume in its fall, and the rock ought to strike the earth that distance away from the base of the tower"

This is an excellent example of the dependence of observation on theory. Since the earth is assumed to be motionless, the vertical motion of the rock is thought to confirm this theory. It should be borne in mind that this interpretation held sway until the seventeenth century. By stepping outside the current paradigm, and considering a theory that was

counter to both the current paradigm and the facts, Galileo was able to uncover the flaw in the tower argument that was invisible from within the Aristotelian perspective. By enticing his readers to consider relative motion on-board ships and coaches, Galileo was able to demonstrate that the observations were in line with the theory that the earth was in motion, and that the Aristotelians confused absolute motion with relative motion. This is an example of truly exceptional scientific inquiry.

The potential advantage of the occasional use of counter induction should now be obvious. No doubt, it is as obvious as the potential harm inherent in its misuse. "There is," it will be objected, "infinite scope for abusing such a methodology. Science may be reduced to an exercise in chasing one's tail." This it true -- yet the danger inherent in a new method is no grounds for its banishment. We advocate Popper's suggestion -- that we retain a critical attitude. This means that the researcher can, with profit, decide when it is time to stay within a current paradigm, or time to step outside it.

Conclusions: Truth, Method, and Education

We began our discussion with the meaning of truth. At this point I believe we are ready to once again address the issue. The pursuit of science has clearly not reached its end. The stock of scientific knowledge continues to grow daily. This knowledge consists of propositions about nature. No one would suggest that nature is ruled by our science -- the propositions of science are held up against nature on a daily basis, and persist or perish based on her judgment. Since the metaphysical question, the question of the existence of absolute truth, need not concern us here, we will limit ourselves to the simple question: do we encourage our students to consider the propositions of science as such, or to view them as the very rules that Nature consults on a daily basis to determine her action.

Hume's refutation of induction is conclusive. That a thing in nature may follow a particular course one thousand times cannot guarantee that it will do so on the one thousand and first trial. Yet this does not take away from the explanatory power of our scientific hypotheses. If science progresses, as Popper believes, through a process of conjecture and refutation, moreover, if scientific theories are good theories in so far as they are testable, then clearly a dogmatic attitude towards the propositions of science can only hinder its advancement.

This idea is unsettling because we like to look at ourselves as the end of history. A little modesty should immediately inform us that we are as prone to error as our forefathers. Our task, as Popper would say, is not to lay claim to the truth, but to eliminate error as quickly as possible. Achievement of this task hinges on our retaining a critical attitude.

The previous chapters have presented an argument in favor of a number of propositions. In the first place, we are not passive mirrors of reality, but actively construct our knowledge of the world. Secondly, our survival depends on action in the face of the unknown, consequently, we have evolved into a species that continually generates hypotheses and acts accordingly. We are not unaware of the results of our actions, and unexpected results inspire us to generate further hypotheses. This chapter considered the advance of scientific knowledge. Science, too, progresses through a process of hypothesis generation in the face of the unknown. These hypotheses are acted upon -- that is, we conduct experiments -- and new hypotheses are generated in the face of the novelty thus released. The further progress of science depends upon our ability to abandon a scientific theory when its explanatory powers have been exhausted and it is obviously contradicted by the facts (see Kuhn, *Structure*, for a discussion on the scientist's reluctance to abandon the current paradigm -- indeed, typically a whole generation of scientists must pass away before an inadequate theory is abandoned). This demands the strength to adopt a critical attitude towards the current paradigm when necessary.

The implications of this for education are clear, and are addressed more fully in the following chapter. Scientific education through a process of conjecture and refutation may not only provide a more appropriate method of teaching than the methods currently employed, it may also engender the kind of critical attitude required of a good scientist -- an attitude which will not shrink, when it is time, from discarding a theory, regardless of how beloved it is, when its usefulness has reached an end.

CHAPTER FOUR

Computers and Education

Knowledge Building

In chapter one we introduced the problem of epistemology, and considered three of the most influential theories in the field, viz. the theories of John Locke, Immanuel Kant, and Jean Piaget. Locke's theory holds that all knowledge comes from the relation of ideas, and that the ultimate source of all ideas is experience. Essentially, for Locke, our knowledge is a true mirror of the external world, and moreover the reflection is passive. Kant's position is diametrically opposed to Locke's. He separates the world as a thing-in-itself from our experience of it and maintains that we only have access to our experience. Our experience, he says, is the result of the active ordering of the mind. This ordering process follows rules that are given *a priori*, that is, independent of experience. Thus the nature and form of all knowledge is determined from within, according to principles of organization which are wholly independent of experience.

After considering these early epistemologies, we examined the work of Jean Piaget. During his study of the cognitive development of children, Piaget recognized that knowledge emerges as a result of two processes -- assimilation of new objects (problems etc.) to existing knowledge structures, and accommodation of these knowledge structures

to the new object. New knowledge comes from the interaction of the subject and the object. Consequently it is midway between the theories of Locke and Kant. To Locke, Piaget would say that new experiences are considered in the light of what is already known, and if possible the new experience is assimilated to the existing body of knowledge. To Kant, Piaget would reply that while the subject actively orders experience, this ordering activity is altered by, or accommodated to, the experience. Consequently the ordering process is not given *a priori*.

Another idea culled from Piaget's theory is that new knowledge is generated through the application of a behavior to a novel object. As Peterson has pointed out, when faced with a novel situation, an organism must react, even though the nature of that action may not yet be determined. The new situation must be explored. In early childhood, a child explores new objects by applying actions that have proved appropriate to other objects. If the action allows for successful manipulation of the object, the new object is assimilated to the action and the action is accommodated as necessary. This is the prototype of typical exploratory behavior -- conjecturing that a particular action will be appropriate for handling an object -- and testing this conjecture. Error is eliminated from the conjecture by refining the action to the new object, or rejecting the conjecture that the action is appropriate.

Hypothesis Generation

Since action in novel situations is, in the worse case, necessary for survival, and action cannot be determined without a leading idea, humans have a natural predisposition to generate hypotheses. In chapter two we examined this tendency over three different domains. In the first we considered the opinions of archaic man. Here we discovered that primitive man seeks a causal explanation for everything. This tendency is so pronounced that chance events are impossible for him. He will believe that an unusual event is the

result of the workings of magic before he will admit the possibility of chance. If he is deprived of a definite cause that he can understand, then he is deprived of the possibility of taking action. Consequently his disbelief in the possibility of chance events may constitute a manifestation of his strong inclination to provide a working hypothesis whenever the unusual occurs. Perhaps this habit is so pronounced because of the hazardous nature of his environment.

The need for a definite explanation also shows itself in the workings of the shaman, or medicine man of a tribe. Aside from being a religious leader, he provides definite causal explanations for illnesses and death. His purpose is to provide working hypotheses, which may seem outlandish to us, and to our mind must seem as such to the shaman. Yet to the people of his tribe, he provides definite answers to seemingly inexplicable events. This reduces the anxiety inherent in the unknown. They may act on this answer. Their actions may be ineffective -- but they may act.

The same propensity to hypothesis generation can be seen in the early days of scientific discovery in Renaissance Europe. The alchemists explained the chemical reactions they observed in terms of religious ideas and religious symbolism. Their imagination suggested to them that a tremendous prize awaited them at the end of their research. They were driven by the hope that they were struggling towards the possibility of generating the perfect substance, or creating an elixir capable of any manner of transformation. Seen from the perspective of the alchemists, neither of these possibilities can be called absurd. They used occult ideas, because these ideas allowed them to begin to explain what they witnessed in their laboratories. While the more glamorous results were never obtained, we have seen that the pursuit of alchemy provided enough useful errors to guide Robert Boyle to found modern chemisry, and Isaac Newton to found modern physics.

Whether or not one considers these so-called useful errors as having helped or hindered the scientific endeavor, there is one result that we cannot deny. When faced with the

unknown, these early scientists did not simply throw up their hands and cry "another black box mystery." They actively explored the unknown with their imagination, and in so doing, made conjectures about the nature of the transformations they witnessed. These conjectures could be tested, and if the alchemist was lucky, the conjecture might help him unearth new evidence. Evidence that may lead him or others to either reject the conjecture or to continue to build upon it. According to Popper and Kuhn, modern science continues to grow in such a fashion.

The final area examined in chapter two is the reaction of modern children to conundrums of experience. Like archaic man, the child endows the objects in his environment with consciousness and life. Occurrence in nature can be explained by endowing the objects in nature with intention. It seems that intentional action does not pose a problem to the child, not at least until it becomes a philosopher. To him, all his actions seem to be due to his own volition. He uses similar ideas to explain other occurrences. When faced with a difficult question the child will guess at an answer -- he will make a conjecture. For example, if he is shown a metal box hung from a wound up double string and asked why, when the box is released, it will turn, the child may answer that the box turns because it is attached to a string that feels itself to be wound up and wishes to unwind itself. Instead of remaining in the dark, the child will suggest an answer. Instead of an explanation in terms of tension and Newton's laws -- the child simply endows the string with intention, and explains that the string, feeling itself to be wound up, simply wishes to unwind itself.

Two implications follow from these observations. First, the natural course of learning may be an active process of hypothesis generation and hypothesis testing. This follows in a line from Piaget's conception of the building of knowledge structures through a process of assimilation: hypothesis generation -- *perhaps behavior x is appropriate for circumstance y*; and accommodation: hypothesis testing -- *behavior x is not appropriate for circumstance y* or *aspects a and b of behavior x are not appropriate for circumstance y,*

but aspects c and d are. If this is the case then attempts to educate through the more traditional, top-down presentation of facts, theories, and opinions, is likely to prove less than optimal.

There is another implication of this propensity to hypothesis generation. When a student approaches a novel problem domain, he does not do so as a passive *tabula rasa*, but rather as an active explorer, and moreover, an explorer with a history. This means that the student may bring any number of prejudices to bear on the new problem. These are the initial attempts at creating working hypotheses. They may be drawn from analogies with other problem domains, or may simply be guesses which are initially more or less useful. Since these initial hypotheses are generated under less than perfect conditions, it is very unlikely that they will amicably fit in with the new information. Typically they clash, and this leads to error, and/or the situation familiar to all educators whereby the student simply cannot begin to grasp the matter of the lesson.

Since learning may be such a process of assimilation and accommodation, the ideal approach may be to allow the student to approach the problem as Piaget believed a child approaches a physical problem. First, there is an initial attempt at assimilation. Previously established behaviors are applied to the new problem as a first pass at classification. The student learns that behaviors *a*, *b*, and *c* are not effective, but after accommodating behavior *d*, it becomes capable of effective manipulation of the object. This has the advantage that the obviously incorrect behaviors *a*, *b*, and *c*, are weeded out and will not interfere at a later stage simply because they have not yet been explicitly addressed. Behavior *d*, as the most appropriate behavior, will serve as an initial starting point. It too has been explicitly addressed, and consequently will not act as an invisible, but real, impediment to further learning.

In other words, when a student is faced with a new problem, his natural reaction is to attempt to solve this problem with ideas derived elsewhere. A number of ideas are brought

to bear on the problem. After a brief period of experimentation, most of these ideas may be explicitly disqualified as ineffectual. The remaining may prove useful, perhaps because they allow a portion of the problem to be broken down, or perhaps because they serve as useful analogies. It is likely that these ideas will be transformed in the process, or perhaps new ideas will be generated through the combination of more primitive ideas. In any case, they act as a starting part, and will aid the learning process according to how directly they lead to a more correct position, or hinder it according to how much they mislead the student. In the former case, ideally the process should be capitalized upon. In the latter, the problem of the misleading ideas must be addressed. Either way, explicit knowledge of the leading idea will prove expedient to the learning process as a whole.

The Scientific Method

In the chapter on scientific methodology, we discussed the growth of scientific knowledge. Specifically we considered Karl Popper's views on the growth of science. Besides this, we reviewed the progress of science under the rubric of a particular paradigm and the dependence of observations on the theory under which the observations are made.

The value of this discussion is three-fold. Firstly, The views of Popper and Kuhn add further weight to the arguments in favor of the proposition that humans naturally generate a hypothesis and act in a manner consistent with the hypothesis. When the hypothesis proves itself to be inadequate, it is replaced by a new one. In its more extreme form, such a paradigm shift constitutes a scientific revolution. At the more day to day level, this behavior finds expression in experimental work.

Secondly, the scientific method may provide a model for education. Typically education is a presentation of facts that are presented in the classroom in a top down format. In the best case, the students grapple with the information as it is presented to them and continue

to do so until they have made the ideas their own. In the worst case the information is simply repeated until it seems to stick. The disadvantages of the latter are obvious, and have already been discussed at greater length. Instead of attaining a comfortable understanding of the ideas, they remain foreign to the student. In such cases the student is reduced to pattern matching. While he still functions according to hypothesis generation and testing, the hypotheses themselves are not directly related to the problem material. They concern formal aspects of the problem. If there are sufficient cues, a prescribed solution method will be applied to the problem. If this hypothesis fails, another prescribed solution method may recommend itself. Learning based on purely formal pattern matching is clearly not the highest goal of education.

The methods of science suggest an alternative approach to learning. If the student approached a new problem domain as an active explorer and experimenter, he may achieve two advantages over more traditional methods. First, his initial prejudices would be eliminated at the early stages. Since these prejudices would form the basis for his initial set of hypotheses, they would be ruled out in so far as they failed to produce correct results. Second, knowledge gained in this way would have a firmer basis. The reason for this is, if the process of learning is hypothesis generation and testing, all hypothesis would come from the subject, and as such they would already be related to the subjects current knowledge structures. The subject's knowledge structures would be accommodated until the new problem has become assimilated. It would no longer be necessary for the student to commit formal patterns to memory by rote, since knowledge structures pertaining to the material itself would have been actively constructed.

The third implication of the discussion of the methods of science for education concerns the education of our scientists. If science does in fact progress according to a process of conjecture and refutation, the advantage of using that method in education is clear. While studying the theory behind a science, the students receive implicit training in method.

Scientists thus trained may acquire critical experimental skills of no small stature. The possibilities are as yet unexplored.

Computers and Learning

The procedure recommended in this thesis is one which allows the student actively explore the material of a new problem domain. However, most educational institutions have neither the time nor the money to allow students to explore even modest experimental methods. Both equipment and expertise are lacking. Advances in computer technology, however, allow for the possibility of moving the laboratory from the physical to the so-called virtual realm.

For some time now researchers have been using simulation methods to explore the possibilities in a particular problem domain. Typically this is done when the problem is too complex for the researcher to rely solely on his intellectual powers. Once the problem is modeled in the computer, the researcher can quickly and easily conduct experiments. By simply changing the value of an input or a parameter he can observe how the computerized model reacts, and make probabilistic inferences on how the actual system may react under similar conditions. The intuitive insights that an experimenter may derive from exploring a computerized model are considerable. Because of the insights which may be derived from using simulation programs, these programs are finding their way into classrooms where they are used for demonstrative purposes. This is becoming more popular across academic and industrial disciplines.

In a simulation, the theory of the problem domain is captured in the program. This programmed theory provides the constraints for the system. Once the constraints are in place, the user may experiment with the virtual system. The user can generate a hypothesis, and design an experiment to test it. If the experiment initially works, the result

may suggest new hypotheses to the student. If the experiment fails, the hypothesis may be discarded in favor of a new one, or it may be modified and tested again. Learning could potentially be converted into a process of exploration and discovery -- a process which can be extremely rewarding.

Limitations

We round off our discussion by briefly considering the limitations of the ideas suggested here. In the first place, many of the ideas were explored in the context of scientific education. The applicability of these ideas to the domains of physics, engineering, and chemistry are relatively obvious, but it is not so clear how these ideas may be useful in teaching such subjects as history for example, or literature. The possibilities would have to be explored at greater length.

Civilization has amassed a huge volume of information. Practical considerations suggest that allowing the student to discover it all anew is infeasible. A mixture of methods of active exploration and top-down presentation of information seems to be the most reasonable initial approach. Other aspects of classroom experience should not be left out of consideration. It is not the intention of the author to suggest that all traditional methods of teaching should be abandoned in favor of experimentation in a virtual laboratory.

EPILOGUE

The current thesis represents an initial attempt to explore the implications of learning through interaction -- through hypothesis generation and hypothesis testing.

In the first place, many of the ideas themselves should be subjected to severe criticism at the theoretical level. The work of more modern cognitive scientists was left largely unexplored by the author. Modern memory theory was also left out of the issue. It is currently believed that humans may possess up to five distinct memory systems: primary, perceptual, procedural, episodic, and semantic (See *Memory Systems 1994*, Schacter and Tulving, MIT Press, 1994). A further theoretical issue that was hinted at in chapter two is the potential role of imagination in learning and research. Many acknowledge the tremendous value of imagination in research, yet few seem as willing to devote effort to the development of this faculty of the human mind. Most educators are far more concerned with training the semantic memory system to store pre-formed hypotheses than training the imagination (episodic memory system? -- see Peterson's *Gods of War*) to reconstruct hypotheses or generate them anew.

The discussion specific to computer use was not sufficiently representative. Perhaps the title of the thesis should be changed to *Learning through Interaction: A Preliminary Study for a Potential Role for Computers in Education*. Once the cognitive aspects of this issue have been further explored, a more detailed examination of the potential role of computers in education should be pursued. Technology continues to race forward, yet our

methods of education have hardly changed at all over the last one hundred years. It is time to reevaluate our methods in the light of this exploding technological advance.

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