EPISTEMOLOGY AND AN INTERACTIVE MODEL OF THE GROWTH OF KNOWLEDGE

1. Introduction :

The most decisive method of testing or evaluating an epistemological theory would seem to consist in seeking an answer to the following set of questions : Whether or not (a) it either implies or suggests a certain model of the growth of scientific knowledge ; (b) the statement of the model is a self-consistent one, i. e., it does not imply a denial of the fact of the growth of scientific knowledge—a fact of great significance about science ; and (c) the model is a useful one, i. e., the model has the useful consequence of rendering the growth of knowledge measurable and evaluable. Such a method can be said to share with the experimental method of science a vital methodological rule which may be stated very generally as follows : That the worth and contribution of a knowledge–claim of whatever level, or of a new idea, or of a theory, must be tested and evaluated in terms of its consequences rather than in terms of its generating sources whatever (cf. (12), p. 221).

An investigation of classical epistemological theories along the proposed method would show them to be either implying or suggesting what might be called non-interactive models of the growth of scientific knowledge, whose statements are self-contradictory and hence which do not satisfy the proposed test-conditions (b) and (c). In order to show that this is actually the case, it becomes necessary to consider first briefly what epistemology is supposed to be concerned with under the classical tradition. In the sections to follow I shall argue and show that, unlike the classical theories of knowledge, Prof. Karl R. Popper's theory of knowledge satisfies all the three test-conditions (a), (b) and (c) as proposed here.

By classical epistemology is to be understood here an age-old philosophical tradition, dominant to this day, under which epistemology is subjectivistically conceived of. Thus under this tradition problems of knowledge and their attempted solutions are sought to be formulated in pragmatical terms such as "belief", "certainty", "doubt", "assertion", "verification", "perceptual experience", "justified belief" and so on. These terms are all pragmatical terms in the modern semiotic sense of requiring reference to a "knowing subject". Most of the contemporary theories of knowledge can be said to belong in this tradition which reappears in them through such problems as the problem of the rock-bottom foundation of knowledge, i.e., the contemporary empiricist problem of the firm empirical basis of knowledge.

Interestingly, the subjectivistic character of classical epistemology explains why it concentrates on knowledge in the ordinary, pre-scientific sense of the term. More precisely it explains why classical epistemology concentrates on problems of knowledge as they arise out of the (theoretical) use of ordinary natural language rather than on those that arise out of the systematic development and use of the language of science.

It is clear that within the classical tradition epistemology does not and cannot *directly* deal with the problem of the growth of scientific knowledge; for the simple reason that problems of knowledge are made to center round a "knowing subject". And most of the contemporary theories of knowledge (such as the logical empiricist theory of knowledge) which go a step further to deal with questions directly arising out of science, retain their traditional classical character by treating the problem of the firm empirical foundation of knowledge as *the* fundamental problem of knowledge. Above all, the classical tradition has had the most undesirable consequence of restricting the contemporary epistemological investigations into science to only a part of what we call science. These investigations leave out of account the most vital part of science, viz., those scientific problems of ever-increasing theoretical interest to which the entire tradition of scientific enquiry owes its existence. In effect, one of the most important aspects of scientific theory is left uninvestigated. This aspect of scientific theory derives from a dynamic interactive relationship between theories and problems in science—a relationship that shows itself up in all scientific problem-situations and that characterizes the pattern of the growth of scientific knowledge.

The point of decisive importance is that the non-interactive models of the growth of knowledge are the only models that one can attempt either to *derive* or to *imagine* under the epistemological theories of the classical tradition (see (8), p. 181). Thus, induc tivism connected with empiricism in its various forms can be regarded as an excellent case of a theory implying a non-interactive model. Since in the inductivist picture of science "observation" and its " data " *alone* are assigned the unique role of " the source and the foundation of all knowledge ", the pattern of the growth of knowledge is, in effect, depicted as a *cumulative* pattern (See (12), pp. 129–130) involving *elements of a single kind* of organization (in this case " observation " and its " data ") which are held solely responsible for the phenomenon of the growth of knowledge. Such a picture of science can yield only a noninteractive model of the growth of knowledge, because, as it will be argued in a later section, it is only elements of different orders of organization and not of a single order of organization that can enter into interactive relationships with each other. Similar non-interactive models can be dervied from the epistemological theories of the rationalist tradition in philosophy; for in their case it is the reason *alone* or the intellect *alone* or the theory *alone* which constitutes the ultimate " source " and " foundation " of knowledge. Since any non-interactive model of the growth of knowledge can be shown to be self-contradictory in character the classical epistemological theories must be rejected because of their failure to satisfy the proposed test-conditions (b) and (c).

Understood as a model that sets a cumulative pattern for the growth of knowledge, the statement of a non-interactive model is bound to be self-contradictory in character. The most objectionable feature of such a model is its inevitable failure to do justice to the historically testified *interactive* pattern of the growth of scientific knowledge, which involves theories, problems, observations, experimentation, critical evaluation and argumentation and so on, all at a time so inseparably that these can, as a rule, be said to form complex wholes with degrees of complexity varying from one such whole to another and from one stage of investigation to another. Thus apart from implying statements about science (e.g. those implied by the empiricist-inductive model of science) that are historically false, non-interactive models cannot account for revolutionary changes in science that have proved to be methodologically vital to an uninterrupted growth of scientific knowledge. It must be admitted that such changes can be brought about by only those interactive forces which can reasonably be supposed to underlie all serious scientific investigation. Under non-interactive models, therefore, the very fact of the growth of scientific knowledge becomes impossible. As it will be argued in our subsequent discussion, it is true of any system of whatever level that without some kind of *interaction* between elements of different orders of organization rather than between elements of a single order of organization there cannot be any change and hence any growth whatever (cf. [5], p. 321).

2. The Cosmological problem and the Growth of Scientific Knowledge :

The problem of the growth of scientific knowledge is closely related to the cosmological problem of understanding the universe including what might be called the " man-world interactive system". The independent theoretical character of the former warrants the evaluation of a proposed epistemological theory in terms of the model of the growth of scientific knowledge which is either implied or suggested by the theory. From the fact that the cosmological problem plays a unique background role for both philosophy and science arises the question of finding an adequate and useful characterization of the *mode* of their respective contributions to cosmology—i.e., to the resolution of the cosmological problem (cf. [15], p. 15). As regards science, this question concerns the function and role of a scientific theory *vis-a-vis* the cosmological problem. It can reasonably be supposed that this question can be adequately tackled in terms of a detailed investigation of what might be called the theory-problem interactive relationship within the specialized fields of science. In this context it is noteworthy that cosmology has been able to make modest beginnings as a science only in this century largely as a result of a growing realization, among scientist and philosophers of science, of its *unilateral* dependence on the specialized fields of scientific investigation. And it is interesting to note that the physical theories proposed within the specialized branches of physics are being increasingly put to a non-customary use of constructing alternative cosmological models of the universe on their bases (cf. [9], p. 527). It is needless to emphasize that this new use of scientific theory in general is bound to lead to a reconsideration of the methodology of its critical evaluation.

The usefulness of a given model of the growth of scientific knowledge of an accompanying evaluative measure of this growth can be tested by considering their use in characterizing adequately the mode of contribution of a scientific theory to cosmology. In the sections to follow the Popperian interactive model of the growth of knowedge will be shown to pass this test by implying as such a measure the concept of the resolving power of a scientific theory—a concept in terms of which the mode of contribution of a scientific theory to consomology can be far more adequately characterized than in terms of any of the customary concepts. This model and its accompanying evaluative measure of the growth of knowledge will be further shown to have important methodological consequences for the critical evaluation of a scientific theory. Thus they will be shown to require : (i) that all such evaluation should center around the resolving power of a scientific theory; (ii) that the customary measures such as the empirical content and explanatory power of a theory, in so far as these are conceived after the classical non-interactive models of the growth of knowledge, must be abandoned as irrelevant; and (iii) that the concepts of these familiar measures be so radically revised or replaced independent of their classical models as to find a use for them within an interactive model of the Popperian type.

The term " resolving power " is borrowed from science where it is frequently used to refer to the ability of an optical system to separate closely related entities such as, e.g., the image of the two stars of a double star in case of telescope, the images of two points lying close together in case of microscope and two spectral lines in case of spectroscope. Here it is proposed to extend this scientific use of the term so as to refer to the ability of a scientific theory to give rise to new problems out of the old ones. Thus when under the impact of a newly invented theory an old problem or a set of old problems is reformulated in new terms, the reformulation involved can be attributed only to the resolving power of the newly invented theory. Because of a unilateral conceptual dependence of cosmology upon the scpecialized fields of scientific inquiry, the concept of the resolving power of a scientific theory is of special relevance to a proper understanding of this relationship. But it is equally important to a proper understanding of the theory-problem interactive relationship within the specialized branches of science.

The way in which and the frequency with which problems are discovered, formulated and reformulated in the process of scientific research and investigation is how an everincreasing resolution of the cosmological problem may be said to take place. Of chief theoretical interest and importance in the growth of scientific knowledge is the progress in the resolution of the cosmological problem. All advances in scientific knowledge that have resulted out of an increasing development of scientific theory in various fields have this chief characteristic of having contributed towards an ever greater resolution of the cosmological problem. This fact lends considerable support to the view to be proposed and defended in this paper, viz., that the excellence of a scientific theory lies neither in *solving* nor in *dissolving* a problem *once for all* but, instead, in its power to contribute towsards a greater resolution of the cosmological problem including those specialized problems that prompt its invention. A theory can be shown to be capable of accomplishing this task by leading to new problems of increased theoretical interest within the specialized fields of science. Thus the resolving power of a scientific theory can be roughly defined as its ability to lead to those new problems of greater theoretical interest which can be regarded as the newly resolved aspects of the cosmological problem including those specialized problems that precede and prompt its invention.

With the cosmological problem forming their common background, science as well as philosophy must be visualized as *starting* with most general theories or points of view as first tentative attempts to resolve the cosmological problem. That is, as specialized ways of investigating and resolving the cosmological problem, they *can* start only with most general points of view or theories including those which get *built into* the decisions to choose and select the objects of a more direct investigation than should be possible without them and with the cosmological problem left to itself. This consideration about the background-role of the cosmological problem will play an important part in our schematic representation of the interactive pattern of the growth of scientific knowledge.

3. Objectivist Epistemology and Popper's Theory of the Growth of Knowledge :

In this section we shall briefly discuss the relevant details of Popper's conception of an objectivist epistemology and his theory of the growth of knowledge with a view to characterize them in as precise terms as possible and as may facilitate their detailed examination in a later section.

In one of his recent essays Popper ([14], p. 365) formulates his conception of an objectivist epistemology as follows :

> Epistemology becomes, from an objectivist point of view, the theory of the growth of knowledge. It becomes the theory of problem-solving, or, in other words, of the construction, critical discussion, evaluation, and critical testing, of competing conjectural theories.

Although this conception can be said to have received its first elaborate expression in Popper's theory of the growth of knowledge as developed and advocated in his book *Conjectures And Refutations* (1963), it is only in the above referred to essay that it is developed in considerable detail. Its great historical significance may be described by admitting that it represents the first interesting attempt ever made decisively to depart from the petrifying traditions of the classical subjectivist epistemology which is inseparably associated with such great philosophers as Descartes, Locke, Berkeley, Hume, Kant and Russell, and, indeed, many contemporary philosophers.

The logical details of this conception are developed by Popper in the form of what may be called a third world argument or thesis. This brings us to his ([14], p. 333) threefold distinction between three objective and relatively autonomous worlds : (*a*) " of physical objects or of physical states "; (*b*) " of states of consciousness, or of mental states, or perhaps of behavioural dispositions to act "; and (*c*) " of *objective contents of thought*, especially of scientific and poetic thoughts and of works of art ". That, apart from their relatively autonomous character, the worlds (*a*) and (*b*) form an interactive system [(*a*) (*b*)] where (*a*) and (*b*) are in mutual interaction by virtue of certain interactive forces is admitted by Popper (see [14], p. 334). Of the third world (*c*) he ([14], p. 334) writes :

> Among the inmates of my ' third ' world are, more especially, *theoretical systems;* but just as important inmates are problems and *problem-situations*. . . .the most important inmates of this world are *critical arguments*, and what may be called—in analogy to a physical state or to a state of consciousness—*the state of a discussion* or the *state of a critical argument;* and, of course, the contents of journals, books and libraries.

Without going into Popper's argument for the reality and relatively autonomous character of this third world (*c*) and the interesting conseuqences thereof, we pass on to his three main theses concerning epistemology, which are put forth and defended in the essay. These are as follows ([14], pp. 337–338) :

(i) that traditional epistemology with its concentration on the second world, or on knowledge in the subjective sense, is irrelevant to the study of scientific knowledge.

(ii) . .that the study of a *largely autonomous* third world of objective knowledge is of decisive importance for epistemology.

(iii) An objectivist epistemology which studies the third world can help to throw an immense amount of light upon the second world of subjective consciousnesss, especially upon the subjective thought processes of scientists; but *the converse is not true.*

To these Popper ([14], p. 338) adds what he calls " three supporting theses " thus :

(iv) . .that the third world is a natural product of the human animal, comparable to a spider's web.

(v) . .the third world is largely *autonomous*, even though we constantly act upon it and are acted upon by it : it is autonomous in spite of the fact that it is our product and that it has a strong feed-back effect upon us; that is to say, upon us *qua* inmates of the second world and even of the first world.

and (vi) ..that it is through this interaction between ourselves and the third world that objective knowledge grows, and that there is a close analogy between the growth of knowledge and biological growth; that is, the evolution of plants and animals.

The question immediately arises : Is there a single concept which can be regarded as central to Popper's objectivist conception of epistemology and hence as committing him to a particular theory of the growth of knowledge ? This question can be answered in the positive as follows :

The above quoted group of theses warrants the view that this central role goes to the concept of *interaction* which is considerably exploited by Popper to characterize (1) the processes within each of the three objective worlds as distinguished by him and (2) the processes arising out of their interactive relationships. The latter may appear in the form of various possible interactive systems such as [(*a*) ←→ (*b*)] or [(*b*) ←→ (*c*)] or [(*a*) ←→ (*c*)] at a time. The processes within the relatively autonomous interactive systems that the worlds (*a*) and (*b*) are respectively form the proper subject-matter of the specialized sciences like physics and psychology. Epistemology must primarily concentrate upon the processes of interaction within the third world (*c*) whose " inmates " can be said to form an interactive system of their own. And it must be admitted that while it is only in this capacity that epistemology " can help to throw an immense amount of light upon the second world of subjective consciousness ", the converse is not true.

Given this objectivist conception of epistemology as the theory of scientific knowledge, we will have now to find out what role, if any, the concept of interaction plays in Popper's theory of the growth of knowledge. In both the first and second editions of his book *Conjectures and Refutations* Popper (see [12], vii, ix) appears to characterize the learning process in general and the process of the growth of knowledge in particular as processes satisfying the principle of feedback control. This characterization is *implicit* in his general thesis concerning knowledge and its growth which he sums up in one single sentence : *That we can learn from our mistakes.* The principles which it is intended to express can be said to be of the same magnitude of significance to philosophy as the principle of feedback control is to the fields of technology and biological and social sciences. This point will be explained fully when we discuss the concept of feedback control in the next section. Here it should suffice to point out that Popper's objectivist conception of epistemology and his general characterization of the processs of the growth of knowledge commit him to a view according to which the growth of knowledge must be identified with the growth of science taken as an interactive system with problems, theories, critical arguments, observations, experimentation and so on as its *elements*. Accordingly, the problem of the growth of knowledge becomes the problem of sorting out the role which each of these elements has in the *dynamics* of the growth of this system.

Popper *implicity* construes the problem in this way when he ([12], p. 222) writes :

> ..we may say that the most lasting contribution to the growth of scientific knowledge that a theory can make are the new problems which it raises, so that we are led back to the view of science and of the growth of knowledge as always starting from, and always ending with, problems—problems of an ever increasing depth, and an ever increasing fertility in suggesting new problems.

A more detailed statement runs as follows ([12], p. 222) :

> Admittedly, our expectations, and thus our theories, may precede, historically, even our problems. *Yet science starts only with problems*. Problems crop up especially when we are disappointed in our expectations or when our theories involve us in difficulties, in contradictions; and these may arise either within a theory, or between two different theories, or as the result of a clash between our theories and our observations. Moreover, it is only through a problem that we become conscious of holding a theory. It is the problem which challenges us to learn; to advance our knowledge; to experiment; and to observe.

These statements clearly imply an interactionist view of the pattern of the growth of knowledge. According to this view the growth of knowledge and hence the functioning of the interactive system of science cannot be identified, at any stage whatever, with the functioning of any one element of this system taken singly. Popper's ([12], p. 222) statement that " science should be visualized as *progressing from problems to problems*—to problems of ever increasing depth ", is only an alternative way of saying the same thing. Especially when considered in the light of Popper's ([12], p. 222) view as to how problems arise, it implies that the growth of knowledge can be identified only with the functioning of the interactive system of science as a whole, where each element of the system is in constant interaction with the other elements (cf. [12], p. 222).

4. Feedback Control and The Principle of Universal Interaction.

An interactive system, whether a mechanical device such as a thermostat or a living organism such as man, is distinguished by a self-regulating mechanism of what has come to be known as feedback control. As a powerfully unifying concept in science, the abstract concept of feedback control is as recent as the science of cybernetics. But as a technological device it goes as far back in history as the third century B.C. when a Greek mechanician named Ktesibios is said to have invented a water clock embodying the principle of feedback control (see [10], pp. 111–112).

According to Norbert Wiener, the founder of Cybernetics, the feedback mechanism " is a method of controlling a system by reinserting into it the results of its past performance " (see [10], p. 111). This is explained by him ([18], p. 107) as follow :

> For any machine subject to a varied external environment, in order to act effectively it is necessary that information concerning the results of its own action be furnished to it as part of the information on which it must continue to act. .This control of a machine on the basis of its *actual* performance rather than its *expected* performance is known as *feedback*. .

Any system, natural or invented, embodying the feedback principle is thus characterized by the fact that the working of the system at a given time is, in the words of Abraham Kaplan ([7], p. 406), " itself a stimulus for the modification of the future course of its working ".

The great unifying power of the feedback principle derives from its key role in the dynamics of growth. All forms of growth and dynamic behaviour in nature are controlled by certain central regulatory processes embodying this principle. Recent recognition of its key role in the dynamics of natural growth has led to its widening applications in the fields of technology, biological sciences and social sciences such as economics and political science. As a result it has become possible for the first time to device economic and political systems with *inbuilt* mechanisms to maintain and regulate their dynamic functioning. Free market system of Adam Smith and the constitutional government are regarded as excelent examples of such systems in economics and political science respectively (see [10], p. 118).

An important consequence of the feedback principle as applied to the dynamics of growth is that a system embodying this principle must be *interactive* in character and *vice versa*. This consequence yields *a* principle of *interaction between elements of different orders of organization rather than of a single order of organization.* A relatively autonomous and dynamic interactive system can thus be characterized as one (*a*) which is constituted out of elements of different orders of organization rather than of a single order of organization with these elements in mutual interaction and (*b*) which has an inbuilt self-regulatory mechanism embodying the feedback principle. It follows that any talk of interaction between any two or more elements of a single order of organization would be a gross misapplication of the concept of interaction. That the radically inductivist and the radically deductivist conceptions of the system of science are excellent examples from the philosophy of science of such a misapplication is quite noteworthy. The former makes use of the self-contradictory idea that the system of science can result or grow from " interaction " between sentences of an observational framework alone. Whereas the latter makes use of an equally self-contradictory idea, viz., that the system of science can result or grow from " interaction " between sentences of a non-observational framework (i.e., theories) alone. In effect, they imply a *cumulative* pattern for the growth of knowledge and a denial of the fact that science forms an interactive system of its own kind.

In view of a very close relationship between the principle of feedback control and the concept of interaction it becomes necessary here to give a very general characterization of the latter as follows. The concept of interaction in the sense implied by the principle of feedback control may reasonably be regarded as the most fundamental concept on which the quantitative methods of most exact sciences rest. Hence the useful role which it can play in adequately distinguishing the quantitative concepts of science from their qualitatively or subjectivistically conceived counterparts in both pre-scientific and non-scientific discourse. For it is true that it is only in and through its quantitative concepts and their accompanying methods of measurement that science is capable of doing justice to what, through its assumptions and results, it tends to reveal as an objectively pervasive feature of the universe. This pervasive feature of the universe may be expressed by saying that the universe is an interactive system on the astronomical scale of the large as well as on the microscope scale of the small (cf. [3], pp. 127–128). The fact that all forms of measurement including observation are a proper sub-class of what may be called "universal interaction", involving varied interactive systems from the microscopically small to the astronomically large, points to the importance of the idea of interaction as a fundamental presupposition of whole science (cf. [18], p. 77).

As a result of above discussion the problem of the growth of knowledge may be construed as a problem of investigating the interactive system of science with whose uninterrupted functioning the growth of knowledge can be identified. It is clear that none of the elements of this system taken individually can serve as a useful object of such an investigation. Yet quite the contrary is assumed to be the case under the classical tradition where it is mostly either " observation " and its " data " *alone* or theory *alone* in terms of which the problem of knowledge is sought to be tackled. It is no surprising consequence of this assumption that the very idea of the growth of knowledge cannot be accommodated in this tradition. For all the modes of the growth of knowledge that one may attempt either to derive from or to imagine under the fundamental assumptions of classical epistemology are essentially non-interactive ones which imply that there is no such thing as the growth of knowledge. The reason behind this self-contradiction hidden in classical epistemology is that the classical tradition violates what we have found to be a fundamental postulate of science on the one hand and a principle of vital importance to the dynamics of growth on the other (cf. [2], p. 89).

5. An Interactive Model of the Growth of Knowledge.

The elements of the interactive system of science, which belongs in the Popperian " third world ", may be divided into two major kinds. To the first kind belongs that *group* of elements which has a direct and a primary role in the functioning of the system. Although the growth of knowledge can be very vaguely identified with an uninterrupted functioning of this system as a whole, for its measure-ability and evaluability the group of elements of the first kind must be specifically taken into account. Here the assumption is that the growth of knowledge can be said to register itself only in the form of the states of this group including the interactive relation-ships that grow within it. Let us refer to this group as $group_1$. Its members are none other than theories, problems and problem-situations.

The rest of the elements of the interactive system of science form another *group* which belongs to the second kind and which may therefore be referred to as $group_2$. The members of this group have an intermediate regulatory role in the functioning of the whole system. Thus their role is comparable to the vital role of a central regulatory feedback control system in the functioning of a mechanical system such as a thermostat or of a biological system such as man. The members of $group_2$ are none other than observations, experiments, measurements, invention and critical evaluation of alternative theories, tentative selection of theories, and perhaps reformulation of problems. The members of $group_2$ are bound by their common function of regulating the dynamic interactive relationship which binds together the members of $group_1$. They can be said to perform this function by means of what Popper calls " evaluative elimination ".

In what follows we shall not go into any details regarding the $group_2$—elements or their interactive relationships. Since we are concerned with the growth of knowledge as such, we shall restrict ourselves to $group_1$—elements, i.e., to theories and problems in their interactive relationship.

Study of how problems and theories interact in each other's discovery, formulation and reformulation can be regarded as the most appropriate way of investigating the interactive pattern of the growth of knowledge. As a rule, problems are not only formulated on the basis of some theory in the background but their reformulation is also frequently necessitated by the impact of newly invented theories. Thus problems in science may be likened to modern space-probing devices whose relationship with their technological matrix (which is involved in their designing and their launching into theoretically chosen orbits) is similar to that between problems and theories. Like space-probing devices which seek new pieces of information, problems function at the same time as *demands* for better alternatives to theories in the background. In this context, what applies in case of theories also applies in the more general case of a language which serves as a general structural background for the formulation of problems in a given field of inquiry. The use of the whole logical structure of a language in the formulation of problems of theoretical interest must involve an implicit use of theories or beliefs which can be said to have preceded, initiated and influenced its development and hence which can be said to have got built into its very structure. Obviously, any slight modification or revision of this structure will have to be preceded by a corresponding revision of the older point of view by means of a better alternative. Thus like a theory, a language is subject to critical evaluation which can be most effectively carried out by developing competing alternatives to it. Such a critical evaluation becomes necessary under a critical approach to the investigation of the theoretical problems themselves.[1]

Popper's own view of the theory-problem interactive relationship can be found in the detailed statement of his theory of the growth of knowledge as developed by him in his book *Conjectures and Refutations* ([12], see section 4 above) and in his recent essay " Epistemology without a Knowing Subject " ([14]). In his latter work Popper ([14], p. 367) writes :

> Thus we can say that science begins with problems and proceeds from there to competing theories which it evaluates critically. . . .

> In most cases, and in the most interesting cases, the theory will ultimately breakdown and thus raise new problems. And the advance achieved can be assessed by the intellectual gap between the original problem and the new problem which results from the breakdown of the theory.

The idea of the pattern of the growth of knowledge as formulated by these sentences is more precisely expressed by Popper ([14], pp. 346, 367) by means of the following schema :

$$P_1 \rightarrow TT \rightarrow EE \rightarrow P_2;$$

that is : problem P_1 – tentative theory – evaluative elimination – problem P_2.

While explaining this schema Popper (14], p. 367) writes :

> The evaluation is always *critical*, and its aim is the discovery and *elimination of error*. The growth of knowledge—and thus the learning process—is not a repetitive or a cumulative process but one of error elimination. It is Dawrinian selection, rather than Lamarckean instruction.

It is interesting to note that the pattern of the growth of knowledge as depicted in the above schema is most emphatically compared by Popper with the pattern of its biological analogue in the organic world of evolutionary growth (see [14], p. 338). Thus describing the above schema as " evolutionary " (see [14], p. 351), according to Popper ([14], p. 346), this schema " gives a rational description of evolutionary emergence, and of our *self-transcendence by means of selection and rational criticism.*"

In view of an overall precedence of theories over problems in science, which Popper ([12], p. 222) himself can be said to admit rather implicitly and which our preceding considerations regarding (i) the background role of the cosmological problem and (ii) the formulation and reformulation of problems in science tend to imply, Popper's schema of the growth of knowledge may be modified in the following manner :

$$BT \rightarrow P_1 \rightarrow TT \rightarrow EE \rightarrow P_2;$$

that is : background theory – problem P_1 – tentative theory – evaluative elimination – problem P_2.

If the contribution and consequences of Popper's theory of the growth of knowledge are to be seriously tested at all then it becomes necessary to give a more precise characterization of this theory than is permitted by such primarily biological concepts as 'evolution', 'selection' and 'emergence'—concepts which Popper heavily relies upon to give a precise expression to his theory. However, it is clear that far from being incompatible with each other, the concept of interaction is of a far more fundamental character than any one of these biological concepts. It is impor tant to note that even the evolutionary pattern of the biological growth with which Popper compares the pattern of the growth of knowledge is embedded in certain fundamental processes of interaction. Thus the evolutionary growth of the organic world as a whole can be said to owe its existence to that interactive system which the organic and inorganic worlds as its elements constitute.

The purpose of a precise characterization of Popper's theory of the growth of knowledge can be, therefore, adequately served if the above schema is interpreted as describing what we propose to call a simplified "interactive model of the growth of knowledge". The theory-problem interactive relationship as depicted in this schema is shown to depend upon a vital interactive process represented by the step (EE) of evaluative elimination. This part of the interactive model can be said to cover the interactive relationships between what we called earlier the $group_1$—elements and the $group_2$—elements of the interactive system of science.

Given an interactive model of the growth of knowledge of above description, mainly two kinds of interactions can be said to keep the system of science functioning. These may be called in-group interactions and inter-group interactions respectively. In-group interactions take place within each of the two—groups of elements of the system distinguished above : $group_1$ and $group_2$ —elements. Whereas inter-group interactions between these two groups are what give the whole system its dynamic interactive character.

In order to consider the consequences of the use of an interactive model of the type under consideration, it is necessary first to make a few clarificatory remarks about the logical status of such a model. It would be a mistake to suppose that a theory of the growth of knowledge and an accompanying model of this growth are concerned with how a generally accepted body of knowledge has *actually* developed. It would be a mistake to suppose so precisely because then a theory of the growth of knowledge would be indistinguishable from a history of ideas. At the most, a theory of the growth of knowledge would function as the *kinematics* of the growth of ideas. But if a theory of the growth of knowledge has to be something interesting and different then it must concern itself with the dynamical problems about the growth of knowledge; such a theory must function as the *dynamics* of the growth of knowledge. And it is only in this capacity that a theory of the growth of knowledge can provide interesting answers to such dynamical problems of central importance as : (*a*) What is the growth of knowledge ? (*b*) How is the growth of knowledge possible ? and (*c*) Does growth of knowledge follow any measurable or objectively evaluable pattern ?

To show how Popper-type interactive model of the growth of knowledge satisfies this description it should suffice to consider the type of answers it provides to the three chief dynamical problems stated above. We shall consider them below in the same order in which these problems have been stated.

(*a*) *What is the growth of knowledge to be identified with* ? The question of the nature of the growth of knowledge is noting but a question of determining the identity of this growth. According to the Popper-type interactive model of the growth of knowledge, this growth must be identified with the changing states of the $group_1$-elements of the system of science, which include the interactive relationships that grow within this group. Thus, in effect, the growth of knowledge is identified with the growth of problems and theories in their mutual interaction. According to this conception the absence of the growth of knowledge becomes identical with a situation in which an already existing theory—problems interactive group is receding in the background, as a result of its interaction with the $group_2$—elements of the system of science, without being replaced by a new group of the same type (cf. [12], p. 241). All problem—situations in science can be regarded as situations of this type. And all such situations must be recognized as potential growth–situations. For when a receding theory-problem interactive group finally leads to the formation of an alternative group a problem-situation is turned into a growth-situation. Historically, first interesting example of a growth-situation is found in Copernican revolution in the field of astronomy. By turning a long existing astronomical problem-situation into a growth-situation, Copernican revolution initiated a process of continual growth which has taken entire science into historically unanticipated directions and made revolutions a part and parcel of *normal science.*

(*b*) *How is the growth of knowledge possible* ? To the question of how is scientific knowledge possible Kant's answer amounted to a principle of interaction between the senses and the intellect, i.e., between the data supplied by the senses on the one hand and the categories of understanding and forms of intuition on the other. But Kant committed the mistake of taking away the dynamic element in this principle by construing the interactive elements as fixed once for all and hence as of a static nature. This enabled Kant to stick to his belief in the absolute truth of Newton's celestial mechanics (see [12], pp. 184–192).

In the context of Einsteinian revolution and the consequent problematical character of Newtonian celestial mechanics, Kant's problem of how is knowledge possible should be reformulated as the problem of how is the growth of knowledge possible. For when nothing in science ought to be accepted as *sacrosanct* and as an absolutely valid piece of knowledge and hence when knowledge becomes identical with the *growth* of scientific knowledge, Kant's formulation loses all theoretical and methodological interest.

From the interactive model of the growth of knowledge under consideration it is clear that the problem of how the growth of knowledge is possible has a very simple answer. The step (EE) of evaluative elimination in this model has obviously the most vital role of maintaining and regulating the process of this growth. In evaluative elimination the $group_1$ and $group_2$-elements enter into inter-group interactions, with the latter group operating as a feedback control system upon the former. It is these interactions which always determine scientific problem-situations as potential growth-situations. Thus growth of knowledge becomes possible because evaluative elimination always makes it possible not only to determine ever new problem-situations on the bases of given theory-problem interactive groups but also to replace them by growth-situations in the form of newly formed theory-problem interactive groups. It is precisely due to the feedback control process of evaluative elimination that in science all problem-situations function as potential growth-situations and all growth-situations as potential problem-situations.

Historically first interesting example of a scientific problem-situation being replaced by a growth-situation is provided by the sixteenth century Copernican revolution in the field of astronomy. In this case the serious difficulties that were faced by the long-dominant geocentric theories of planetary motion *determined* the astronomical problem-situation which the Copernican revolution replaced by a growth-situation in the form of the heliocentric theory as an alternative solution to the Greek problem of " how to explain the apparant movements of the heavens in terms of motions that were circular and uniform " (Cf. [11], p. 101). It is interesting to note that in the beginning of the seventeenth century, the Copernicus' version of the heliocentric theory came under a process of evaluative elimination which was carried out by Johannes Kepler. Inspired by the characteristic accuracy of the astronomical measurements of Tycho de Brahe, the famous sixteenth century Danish astronomer, Kepler was perhaps the first to realize the need for deriving accurate predictions from the heliocentric theory. This was demonstrably impossible so long as the theory incorporated the Greek assumption of the circular and uniform character of planetary motions. Kepler eliminated this Greek ingredient of the heliocentric theory and discovered his famous three laws of planetary motion, two of which asserted the elliptical and non-uniform character of planetary motions (cf. [11], pp. 106–107, 125.)

How a new astronomical problem-situation arose out of the heliocentric theory and the observations of Tycho de Brahe is best expressed by Brain Ellis ([1], p. 40) as follow :—

> The planetary theory of Kepler, and thus, ultimately the astronomical observations of Tycho de Brahe, had created the need for a non-homocentric system of dynamics. When it became no longer possible to accept that the earth was

the centre of the universe, a system of dynamics that was not earth-centered was clearly needed. The homocentric dynamics of Aristotle were an anachronism in the heliocentric universe of Kepler.

This new problem-situation was left, as history would have it, to Newton to tackle, which he did by discovering the three fundamental laws of classical dynamics—Newton's laws of motion. Newtonian mechanics involving his famous law of universal gravitation was similarly preceded by a whole problem of assigning a mechanical explanation to the motions of the planets. Galileo's researches into terrestrial mechanics showing " that the gravity of the earth bent the inertial motion of a projectile into a parabolic path " had significantly raised this new mechanical problem (cf. [11], pp. 123, 128 and [19], p. 148).

6. The Resolving Power of a Scientific Theory.

Does the growth of knowledge follow any measurable or objectively evaluable pattern ? So far as the interactive model of the growth of knowledge is concerned, this question must be answered in the affirmative. This question therefore, reduced to the question : What concept/concepts may be adopted as an objective evaluative measure of the interactive pattern of the gwowth of knowledge ?

Our discussion so far warrants the introduction of a new concept, viz., the concept of the *resolving power of a scientific theory* as *a* measure of the growth of knowledge. This does not imply that the customary measures such as the empirical (informative) content and explanatory power of a theory must be abandoned in favour of the newly adopted measure. Since the former have been mostly conceived under and associated with the customary-non-interactive models of the growth of knowledge (such as, e.g., the inductive model) only a radical revision of our concepts of these measures is necessitated by the interactive model. Popper again makes an interesting exception in this case in that his concepts of the customary measures are distinctly non-traditional and in consonance with his theory of the growth of knowledge (see [12], pp. 385, 391; [13], pp. 286–287; [15] pp. 119–121).

Popper's own suggestive idea of " assessing " the advancing steps in the growth of knowledge in terms of " the intellectual gap between the original problem and the new problem which results from the breakdown of the theory" (see (14], p. 367) unambiguously points in the direction of the concept of the resolving power of a scientific theory as *a* measure of the growth of knowledge. The proposal to adopt this concept as such a measure is thus clearly warranted both by the interactive model considered above (section 5) and by our earlier considerations regarding the role of the cosmological problem (sec. 2).

The concept of the resolving power of a scientific theory as a measure of the growth of knowledge can also be shown to be implied by one of Popper's ([12], pp. 241–242) three requirements for the growth of knowledge. The three requirements as formulated by Popper are: (1) "The new theory should proceed from some *simple, new and powerful unifying idea* about some connection or relation (such as gravitational attraction) between hitherto unconnected things....or facts....or new 'theoretical entities'...."; (2) "....the new theory should be *independently testable*....'; and (3) "the theory should pass some new, and severe, tests" (see [12], pp. 241–242). The requirement (1) essentially requires a scientific theory to possess adequate *explanatory power* such that it explains all the *explicanda* which it was designed to explain (see [12], p. 241). The requirement (2) of independent testability as explained by Popper requires that a scientific theory should *also* "have new and testable consequences (preferably consequences of a *new kind*)"; that "it must lead to the prediction of phenomena which have not so far been observed" (see [12], pp. 241–242). This requirement can be said to require, in effect, that besides possessing adequate explanatory power, a scientific theory should also possess adequate resolving power such that it can suggest new experiments, new tests and hence lead to new problems. This interpretation is amply supported by Popper's own view of the requirement of independent testability. To quote Popper ([12], p. 242):

> ....the second requirement also ensures that our new theory will, to some extent, be fruitful as an instrument of exploration. That is to say, it will suggest to us new experiments, and even if these should at once lead to the refutation of the theory, our factual knowledge will have grown through

the unexpected results of the new experiments. Moreover, they will confront us with new problems to be solved by new explanatory theories.

Like the requirement (3) of "empirical success", the requirement (2) of independent testability is regarded by Popper as indispensable. Their indispensability is said to consist in their ruling out from science "trivial" and *ad hoc* theories ([12], pp. 241, 244).

To illustrate how the resolving power of a scientific theory might be visualized, let us consider a very simple example of Darwin's revolutionary theory of organic evolution. This theory may be said to derive its revolutionary character from its recognition of the organic world as a feedback control system that is self-regulating. Because of the simple fact that the organic world owes its dynamic character partly to its participation in the interactive system of the entire universe, Darwinian revolution crosses the boundaries of the biological sciences and penetrates deep into the field of physical sciences whose theories are generally of a direct relevance to the cosmological problem. It may not be thus surprising to find the concept of evolution being applied on the astronomical scale in various cosmological models scientists have constructed in this century. Both the "Big-bang" and "Steady-state" models of the universe are examples of such an application. Both these models employ the idea of an evolving universe.

This shows that the scientific relevance of the concept of evolution as Darwin conceived it is not exhausted by its merely *explanatory use* to which it is put in the biological sciences. On the contrary, crossing the boundaries of the sciences of its origin, the concept of evolution proves of a high resolving power in its current use both in the formulation of the cosmological problem and in the cosmological models that have been developed as attempted solutions to this problem.

Before considering the resolving power of a scientific theory as a measure of the growth of knowledge further in terms of its important methodological implications for science, the following historical remarks deserve some consideration. Historically, it is true that a constant increase in the resolution of scientific problems has been registered largely as a result of a constant development of scientific theory. This is also true of science as a *whole*. Thus the prominent stages in its historical development are noteworthy: the gradual evolution of science into an independent and an autonomous tradition of inquiry, free from the grip of ancient philosophical traditions; the gradual development of science into relatively autonomous specialized fields of inquiry; and, subsequently, their increasing tendency to multiphy further in the direction of on increasingly specialized inquiry. Such a growth can be attributed mainly to an overall change in the older intellectual values, beliefs, theories, problems and methods of inquiry and their replacement by new alternatives.

Thus we can reasonably say that the history of the various branches of science such as physics is a history not of how certain problems may be said to have been "solved" once for all by means of certain theories, but of *a constant interaction between theories and problems with frequent feedback consequences for each other*. It is thus a history of intellectual progress which is characterized by frequent transitions from highly complex and ambiguous problems to increasingly simpler and precise ones. Even the development and division of science into increasingly specialized fields of inquriry excellently illustrates a process in which there is a gradual and sometimes a quick transition from a set of complexer problems to a set of simpler ones. Thus if our scientific knowledge can be said to have registered any *substantial* and *lasting* growth over different periods of the historical development of science, then it consists chiefly in the fact that the present-day scientific theory generally possesses a far greater degree of resolving power than the older theory did. That is to say, in other words, the present-day scientific problems are the highly simpler, precise and hence greatly *resolved* versions of their highly complexer and ambiguous *ancestors*.[2]

It is equally reasonable to say that the ever increasing resolving power of a scientific theory also shows itself up in its direct technological consequences for the development and designing of increasingly sensitive experimental devices that are *in turn* used in the testing of its explanatory and predictive power. Thus, for exaexample, the sensitive character of experiments that are designed from time to time to determine the numerical values of the fundamental physical constants " to ever greater levels of accuracy " is intimately related to the resolving power of the basic physical theories in which these constants occur (see [17], pp. 63–66; 77–78).

We may now turn to consider briefly the methodological consequence of adopting the resolving power of a scientific theory as a measure of the growth of knowledge. In section 5 above it was suggested that all specific problems of theoretical interest must be construed as demands for better alternatives to the theories in the background. Thus, construed, it becomes clear that their discovery and formulation presuppose and largely depend upon the theoretical context provided by these background-theories. Thus their initial formulation must always be treated as *tentative* owing to the very character of the problem-situation of which they are a part. And, when alternatives (the so-called " solutions " in the customary idiom) are discovered and developed, their feedback consequences for an improved reformulation or resolution of the original problems into simpler and precise versions must be investigated before any other conclusions are drawn. On the basis of this simple consideration, we may propose, as a methodological rule, that the critical evaluation of a scientific theory must not remain restricted to the customary concepts of its empirical content or explanatory power; but, instead, it must go beyond these to evaluate its feedback consequences for an improved reformulation and resolution of those problems that prompted its discovery.

Our consideration, in section 2 above, of the cosmological problem *vis-a-vis* the growth of knowledge strengthens further the above stated methodological rule. With the cosmological problem in the background, the idea of the resolving power of a scientific theory makes excellent sense, especially in connection with the problem of characterizing adequately and very generally the *mode* of contribution of a scientific theory to cosmology. The way the cosmological problem gets increasingly *resolved* into more and more specialized problems, as a result of a constant development of specialized scientific theory, may be said to yield such a characterization. Hence the importance of the resolving power of a scientific theory as a measure of the growth of knowledge. Such a measure is thus methodologically important in that it permits critical evaluation of a scientific theory taken in its two-fold relationship with the specialized problems within science and with the cosmological problem.

7. Concluding Remarks:

In conclution we may say that two most important (functional) aspects of a scientific theory are : (1) its explanatory power with which it " solves " older, *antecedently known* probldems and (2) its resolving power with which it gives rise to newer problems out of the older ones. Thus the familiar concept of the explanatory power of a theory can be regarded as appropriate to all those contexts in which a problem or a set of problems prompts the discovery of a theory or theories as its attempted solution. But this concept *cannot* take care of the other more important function of a scientific theory, viz., the fonction of giving rise to ever new problems or making an ever greater resolution of the cosmological problem possible. Thus the proposed concept of the resolving power of a scientific theory can be regarded as most appropriate to all the contexts of *problem-resolving* in science. The explanatory power and the resolving power of a scientific theory thus turn out to be essentially interactive concepts referring respectively to the interactive processes of *problem-solving* and *problem-resolving* in science. These two concepts together with the concept of the empirical content of a scientific theory may be said to constitute *the* evaluative measure of the growth of scientific knowledge.

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NOTES

A previous version of this paper was read at a meeting of Teacher's Seminar of Philosophy Department of Visva-Bharati, Śantiniketan, sometime in the Autumn of 1971.

1. For an interesting, though brief, treatment of the question of the role of language in the formulation and solution of problems see ([4], pp. 183–186 and the footnote (151), pp. 254–257); and cf ([12], p. 129).

2. The word "resolution" or "resolving power" is invariably used in this paper in the sense as defined in section 2 above. It is interesting to note that certain recent re-interpretations of (1) measurement in science and (2) the growth of knowledge in information-theoretic terms such as the *quantity of information* come very near the concept of the resolving power of a scientific theory as proposed here (see [6], pp. 4; 87–88; 102–107).