THE INTERROGATIVE MODEL OF INQUIRY AS A LOGIC OF SCIENTIFIC REASONING

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Questioning has been understood as a general method for knowledge seeking in philosophy for thousands of years. The first systematic questioning approach in the (written) history of philosophy is the Socratic Method of Questioning (elenchus). The strategy of questioning is the central part of the Socratic Method of Questioning. Hintikka has developed a logico-philosophical model called the Interrogative Model of Inquiry, in which he systematizes the questioning method. The notion of strategy plays central role in the systematization. The deductive logic offers a strategic ideal for all human rational reasoning.

Key words: interrogative model, logic, method, strategy.

Introduction

Questioning is a usual way for human beings to get the information they need. If someone wants to know what the time is, he or she asks someone else for the time. The questioner addresses the question to someone whom he or she assumes to have the desired information. The answerer is assumed to give the information the questioner is looking for such that the answer allows the questioner to say truthfully that he or she knows what the time is. Of course, all this is obvious, and maybe this might appear to be too obvious to be of any interest. However, that is not true.

Questioning has been understood as a general method for knowledge seeking in philosophy for thousands of years. The first systematic questioning approach in the (written) history of philosophy is the Socratic Method of Questioning (*elenchus*). The strategy of questioning is the central part of the Socratic Method of Questioning. The reason for the importance of the strategy is that the class of questions the questioner is allowed to ask is restricted due to methodical reasons. For example, in the search for the extension of a given notion, the questioner is not allowed to directly ask for the searched extension. To directly ask for the extension is a strategic mistake referred to as *petitio principii* or begging the question. This mistake is not a logical mistake but rather an interrogative mistake in which the character of the questioning method is trivialized [10; 11; 16; 17; 20].

Aristotle systematizes the (Socratic) questioning method in his philosophy. In *Topica,* Aristotle characterizes a systematic approach to different kinds of questioning situations [10; 15]. Moreover, Aristotle recognized that in a series of questions, there are two different kinds of questions: Questions whose answers are determined by the information the questioner possesses before the question is asked and questions whose answer supposes some further information. The analysis of the first kind of questions ends up in Aristotle's syllogistic. And the analysis of the second kind of questions ends up in the strategic analysis of different kinds of question-answer sequences [10; 8; 5].

Bacon was one of the first to generalize the questioning method in his analysis of experimentation [10]. In an experiment, the idea is that the inquirer is asking questions from nature. The experimental set-up has to be built up such that the needed information can be obtained. However, in the case of an experiment, questioning is merely metaphorical: nature cannot be a participant in a proper dialogue. In a question-answer dialogue, say in a courtroom, the used language is our ordinary language. More generally, we assume that all the participants in a question-answer dialogue will have a (more or less) common language. It is not obvious what the language of nature is [23].

Kant emphasized the strategic aspects of questioning. The inquirer is not a passive observer but an active searcher who compels nature to answer the questions planned by the inquirer. The plan of questioning has to be strategic. The inquirer plans a sequence of questions intended to reveal the information needed. The essential thing is to have a strategically planned sequence of questions, not questions as such. The intended knowledge is constructed by the information obtained through the strategic questioning. Such a structured plan allows us to avoid the *petitio principii* mistake. The structure of scientific research is a many level process in which questions operate at different levels [23; 10; 9].

Hintikka has developed a logico-philosophical model called the *Interrogative Model of Inquiry*, in which he systematizes the above observations. The Interrogative Model of Inquiry is intended to be a general theory of all reasoning or '*the* theory of reasoning, logical as well as empirical, comprising deductive logic as a special case' [12]. So, the idea is to develop a system of logic in which asking a question, understanding an answer and drawing an inference would be treated on a par.

Hintikka's idea is to develop a proper logical model of "the activities of seeking and finding". The use of formal logical methods goes against the present current in philosophy; Hintikka thinks that the problems can be solved by using stronger logical tools. The Interrogative Model is a proper logical model in which the notion of strategy plays the most central role as, for example, one can see from the *Strategy Theorem* or from the *Yes-No Theorem* [12].

Interrogative Model

Let us take a closer look at the Interrogative Model. Let L be a first order. Let T be a theory in L and let **A** be any infinite model of the theory T, $\mathbf{A} \models T$. (For further information about the notation see, for example, [13], [7], and [8].) Let F be a formula of L. We say that F can be *interrogatively derived from T in **A***, if we can deduce F from T together with some auxiliary information from the model **A**. We denote this as follows:

$$\mathbf{A}{:}T \vdash F \qquad (1)$$

which can be read as 'the formula F can be interrogatively derived from the theory T in the model **A**'.

The formula (1) shows several aspects of the Interrogative Model. From (1) we can see that the underlying logic of scientific reasoning is the usual deductive logic. Deductive logic is used in recollecting and explicating existing knowledge, not in the proper search for new knowledge. Hence, the ampliativity of scientific reasoning is not a property of the underlying logic. The ampliativity has to be built, in one way or another, into the reasoning process.

To get further information for the inquiry process, the inquirer may ask questions about the underlying model **A**. The answers are about the model or in applications about the reality under inquiry — hence the answers are empirical. The empirical information brings new information into the reasoning process. Especially, the ampliativity is the outcome of the method of acquiring additional information. That is, the ampliativity is not connected to some specific piece of information but the whole method of acquiring information. That is, the ampliativity of the scientific reasoning is part of the whole strategy of the inquiry process. Hence the notion of strategy plays an extremely important role in the Interrogative Model [9; 10; 23; 14].

To explicate the logic of the formula (1) we have to specify the information the inquirer may — in principle — get during the inquiry process. The specification can be done in a logical way by restricting the logical complexity of the answers that the inquirer may get. In the simplest case, the answers are restricted to the truths expressed by atomic (quantifier free) sentences. Logically this means that the answers will be members of the *diagram* of the model. This restriction will be called the *Atomistic Assumption* or the *Atomistic Postulate*.

It is quite natural to accept the Atomistic Assumption in pure observational science: observation tells us how things are here and now, not how they are in a general case. However, the Atomistic Assumption was quite generally accepted as a philosophical foundation in the philosophy of science in the early 20th century. The logic that we get by accepting the Atomistic Assumption is the model theoretical logic developed by Abraham Robinson. That is, the ideal theory is not a complete theory (as it was for logical positivists) but a model complete theory. The notions of completeness and model completeness are different notions. This already shows the philosophical and logical importance of the Interrogative Model [6; 13]. By allowing more complex answers we get a hierarchy of different interrogative logics. The hierarchy is called the AE-hierarchy, referring to the complexity of the quantifier prefix of the answers allowed [7; 23].

The logic of experimental science is an interesting special case of the Interrogative Model. In an experiment, the inquirer is looking for functional relationships between variables. For simplicity, let us assume that in an experiment there are two variables, say x and y, whose functional dependency is sought. The question is, how does the observed variable y depend on the controlled variable x? By accepting the Atomistic Assumption we get the Humean problem of induction. However, in experimental science the Humean problem is not recognized as a problem at all: no empirical scientist thinks that the Humean problem is something they should solve before they can do proper scientific inquiry. The Interrogative Model expresses a logic of experiment that shows how to avoid the (misleading) Humean problem [10; 23].

The formula (1) shows that the interrogative logic is between the usual deductive logic and the truth in a model. If the inquirer does not ask any questions then the role of the model becomes vacuous. This means that the formula (1) reduces to the usual deduction:

$$T \vdash F. \qquad (2)$$

The formula (2) can be read as ‘F can be derived from the theory T’. That is, interrogative logic is a generalization of the usual deductive logic; deductive logic is a special case of interrogative logic in which no questions are asked.

If there is no restriction as to what questions can be answered there is no reason to refrain from asking the initial question of inquiry at the beginning. This would make the inquiry a very simple task to do [E.g. 9; 11; 16]. Logically this means that in the formula (1) the role of the theory becomes vacuous and the formula (1) reduces to the truth in the model:

$$\mathbf{A} \models \mathrm{F}. \tag{3}$$

The formula (3) can be read as ‘F is true in the model **A**’. In inquiry, the background knowledge — coded into the theory T — is not good enough. The knowledge is always incomplete and there is a continuous need for further study. However, the sources of information are not or cannot be unrestricted. The logic of inquiry is interrogative logic in which the inquirer uses both the background knowledge and the auxiliary information in his or her inferences. The inquirer has to know the background knowledge and the available sources of auxiliary information. The task of the inquirer is fundamentally strategic: there are no (mechanical) rules that would tell the inquirer what to do; he or she has to have a strategy that leads the inquiry process [10; 11; 12; 16].

Scientific method

The name of Alan Chalmers’ book *What Is This Thing Called Science*? manifests a problem of central philosophical importance. Feyerabend 1988 answers this question by stating that it “has not one answer, but many. Every school in the philosophy of science has special views about the nature of scientific activities while there are large areas where the scientists themselves show little unanimity” [1. P. 256]. According to Feyerabend, this is a very disastrous situation. The question does not have a unique philosophical answer: philosophy cannot help us. However, practice does not help us either: the practical answer would be that “science is what I am doing and what my colleagues are doing and what my peers and the public at large regard as ‘scientific’. Given this situation it does not surprise us at all that there is ‘scientific’ wrestling and ‘scientific’ dogfood” [1. P. 257].

The conclusion Feyerabend arrives at is known as his *methodological anarchism*. The only rule that methodological anarchism accepts is that *anything goes*. “Neither facts nor methods can establish the excellence of science. Methods cannot do that because there is no uniform ‘scientific method’. Facts do not establish it because it is not facts that count, but the importance of facts” [1. P. 258]. In his critique, Feyerabend carefully considers several historical examples, takes some fundamental ideas from the philosophy of science, and puts the two together. This method demonstrates that the history of science has many faces: science is manifold. Philosophical inquiry cannot be a search for some unique rule or some unique algorithm (or procedure) that is followed in every singular case of the scientific inquiry.

Feyerabend’s critique against the method of science is very important. It seems to be highly conclusive: there is in fact no single method in science. However, the argument is not conclusive. To find out a method that solves a given problem demonstrates that there exist a solving method for the problem. The negative case is not similar: to falsify existential sentence is not so easy task to do. To characterize the problem introduced by Feyerabend we need more general notion of scientific method.

To pinpoint the argument, let us briefly consider the history of mathematical reasoning. In the history of mathematics there is a long tradition in which the notion of algorithm played a central role. Several different algorithms have been explicated. Some of them are well known. Each algorithm is a solution to some specific class of problems. To show that a given class of problems is solvable, the only possibility was to explicate an algorithm that solves that class of problems. Unfortunately the method did not help if the given class does not have an algorithm that would solve the problems of the class [17].

In 1936, Turing, in a sense, completed such an approach: he formulated general machinery that explicates the notion of algorithm [24]. Turing formulated a general notion of computation — Turing machine computation. The formulation was brilliant in several ways. The formulation was formally exact. The applicability of the formulation is very good, as the history of computers shows.

In the 1930s, Turing was not the only logician who was searching for a formal definition of the notion of computation. Gödel formulated the notion of computation by using the notion of recursivity, which is part of a younger tradition of inductive definition arising from Dedekind's precise formulation in 1888. To sum up, the 1930s saw the publication of several different formulations of the notion, namely: recursivity (Herbrand, Gödel, Kleene), λ-definability (Church, Kleene, Rosser) and (Turing) machine computability (Turing, Post). Remarkably, all of them have been proven to be equivalent, which is understood to give strong support for Church's Thesis: An intuitive notion of computability can be identified with the notion of recursiveness [17; 24].

The notion of computation is not a single method — for each class of problems we have to either write a Turing machine program or define a recursive function that solves the given class of problems. However, we have a universal Turing machine into which the programs of all the other Turing machines are coded. The notion of computation does not help us in actual computation but helps us to characterize all the possible programs in a single general program. Especially the formal definition of computability made it possible to prove the famous incompleteness theorems in logic [24].

The search for a method of science should be at a similar level. In fact, the emphasis of the notion of strategy in the Interrogative Model is at this level. The notion of strategy allows us to characterize the solvability of the given class of scientific problems. The notion of strategy allows us to characterize explicitly the notion of scientific method. Moreover, this strategic view interconnects different philosophical approaches [10; 11; 3; 4; 16; 20; 2].

In this, the Interrogative Model is part of the wider approach in logic and philosophy that can be called 'dynamic turn' in logic and in philosophy. The dynamic turn is not a single discipline but a collection of several different approaches that emphasize strategic and practical aspects of logical study. Let us mention dynamic epistemic logic (van Benthem), formal epistemology (Kelly), formal learning theory (Osherson) and modal operator epistemology (Hendricks). In all these approaches, the emphasis is the same: understanding scientific reasoning as a process in which the inquirer is looking for new knowledge through asking questions. Even if there are differences between the formalisms used, the fundamental philosophical orientation is the same in the models [2; 4].

Logic of experiment

For a better view of the logic of the Interrogative Model let us consider the logic of experiment. In an experiment, the inquirer is not a passive observer but an active searcher who compels nature to give the information the inquirer needs. In the Interrogative Model, the logic of experiment is characterized as a questioning-answering process. The questioning strategy of the inquirer is intended to be goal tracking — especially, in basic science, truth tracking. Such a strategy can be called a forcing method [6; 10; 3; 4]. Here we have a close interconnection with the dynamic turn in philosophy.

The experimental question looks for functional dependencies between variables: how does the variable y for a certain quantity depend on another one, say *x*, for a different variable? As the goal of an experiment, the experimenter knows the function that expresses the asked dependence. The experiment should give the information that allows the experimenter to identify the intended function. Logically this can be expressed as follows:

$$\mathrm{K}(\exists \mathrm{f}/\mathrm{K})(\forall x)\mathrm{S}[x, \mathrm{f}(x)] \tag{4}$$

where ‘K’ is the knowledge operator and slash ‘/’ is the independence operator. That is, the experimenter has to ascertain the function f, which gives the interconnection between the variables. The formula (4) expresses that the knowledge is knowledge about a mathematical object. The knowledge is independent of the specific epistemic scenarios of the inquirer. This independence is expressed by the use of the slash operator [23].

Ideally, the experiment gives only the function-in-extension. That is, a (infinite) sequence of ordered pairs that gives the graph of the intended function. Let g be the function-in-extension. So, the experiment then gives the observational answer:

$$\mathrm{K}(\forall x)\mathrm{S}[x, \mathrm{g}(x)]. \tag{5}$$

Unfortunately, in general, (5) does not imply (4). Even if the experimenter ascertains the function-in-extension he or she does not necessarily find out the mathematical identity of the function. The information that allows the experimenter to identify the function-in-extension mathematically is needed; this is called the conclusiveness condition of the answer. The conclusiveness condition can be formulated as follows:

$$\mathrm{K}(\exists \mathrm{f}/\mathrm{K})(\forall x)(\mathrm{g}(x) = \mathrm{f}(x)). \tag{6}$$

The formula (6) gives the information the experimenter needs: the experimenter knows the mathematical identity of the function. The knowledge is a kind of factual — *de re* — knowledge about the function. Logically this means that (5) together with (6) implies (4). The knowledge of mathematical identity of the function gives the needed conclusiveness condition.

The knowledge expressed by (3) is of conceptual or, rather, mathematical character. It is knowledge about the identity of a mathematical object. To get the knowledge, the experimenter does not need to make any further experiments or observations but rather engage in mathematical reasoning [10. P. 125—126]. This shows how mathematical knowledge comes into the structure of empirical science. The mathematical knowledge is part and parcel of answering experimental questions. By and large, this provides general information about an empirical inquirer's ability to answer experimental questions and a general philosophical characterization of experimental inquiry [10; 23; 18; 19].

Quine emphasized that factual, linguistic and other conceptual knowledge are inseparable [e.g., 21; 22]. However, such an inseparability thesis makes it impossible to see the deep interconnection between two notions of knowledge. The Interrogative Model of Inquiry throws new light on the interconnection of these kinds of knowledge. The inseparability is built up into the entanglement of the kinds of knowledge in our epistemic practices — asking and answering questions. According to the analysis there seems to be only a single notion of knowledge, which is referred to by the symbol 'K'. It is important to study the use of the two notions of knowledge [10].

The role of the conclusiveness condition of the answer is extremely important. We recognized that basically it is conceptual knowledge. Such knowledge organizes the empirical knowledge. Hence it cannot be based on the experimental information; it is a kind of *a priori* knowledge [10]. Humean induction is a kind of blind induction in which empirical information is generalized, following various inductive rules. According to the analysis above, the *a priori* knowledge organizes the empirical information. The *a priori* knowledge is bound in the whole process of inquiry: the basic questioning is already organized. However, the functional identity becomes clear only at the end of the inquiry process. According to the analysis, the inductive reasoning seeks to determine the function-in-extension and to identify mathematically the function-in-extension. The first is reminiscent of Humean induction. However, the proper task of experimental inquiry also includes a second step, the identification step. Hence the structure of induction becomes very complicated [23].

Logic of discovery and justification

In the Interrogative Model, it is assumed that the answers are true and known to be true. Even if this is not a realistic assumption, it is often made in philosophy [23]. In the Interrogative Model, it is easy to see that the assumption implies that the results derived by the Interrogative Model are true and are known to be true. This means that the Interrogative Model shows how to find out experimental truths. However, this can be called a logic of pure discovery [12].

Unfortunately the assumption made is not a realistic one. What happens if we also allow unsecure and possibly false answers? The final goal will not be changed: our intent is still to arrive at truthful knowledge. The logic of pure discovery does not work anymore. We have to develop the logic of justification. This can be done within the framework of the Interrogative Model by allowing one more operator, an operator that denotes the unsecurity of some piece of information: 'What we need is a rule or rules that authorize the rejection — which is tentative and may be only temporary — of some of the answers that an inquirer receives. The *terminus technicus* for such rejection is *bracketing*. The possibility of bracketing widens the scope of epistemological and logical methods tremendously. After this generalization has been carried out, the logic of interrogative inquiry can serve many of the same purposes as the different variants of non-monotonic reasoning, and serve them without the tacit assumptions that often make non-monotonic reasoning epistemologically restricted or even philosophically dubious' [10. P. 20]. Justification and discovery both have to be understood as part of the same process of inquiry. The strategies of this whole process serve both purposes. So, in this deeper strategic sense, there is only one logic of scientific reasoning [7; 10; 23].

The use of the bracketing rule is not a task of a philosopher but an empirical inquirer. The determination whether or not the forthcoming information is reliable is not a logical or a philosophical task. There has to be empirical knowledge about the sources of information. In empirical science, the long tradition of research on experimental set ups is an essential part of this evaluation of the sources of information. All reasonable and profound critique is important. The evaluation process is an unending process. In this respect Feyerabend's critique is very welcome.

We have seen that deductive reasoning has a fundamental role in scientific reasoning. It offers a strategic ideal for all human rational reasoning [10; 12]. However, the strategic role of deductive reasoning requires further study. This study also throws new light on the role of inductive reasoning. In a sense, the Interrogative Model allow us to characterize inductive problems so that they will be solvable within a finite period of time and, hence, in a sense, make inductive problems essentially deductive inferences [9; 10; 17; 4]. The study of strategies of questioning will shed new light on this problem.

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ИНТЕРРОГАТИВНАЯ МОДЕЛЬ ИССЛЕДОВАНИЯ КАК ЛОГИКА НАУЧНОГО МЫШЛЕНИЯ

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На протяжении нескольких тысяч лет философских поисков вопрошание понималось как общий метод познания. Первым систематическим исследованием формулирования вопросов в истории философии (письменно зафиксированным) является сократовский метод (elenchus). Стратегия формулирования вопросов составляет основу сократовского метода вопрошания. Хинтикка развил логико-философскую модель, получившую название «интеррогативная модель исследования», в которой метод формулирования вопросов получает систематическое выражение. Понятие стратегии играет центральную роль в этой систематизации. Дедуктивная логика оказывается стратегическим идеалом для всех человеческих рациональных рассуждений.

Ключевые слова: интеррогативная модель, логика, стратегия.