Humankind and the Environment: An Anatomy of Surprise and Ignorance

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ABSTRACT: This paper addresses the problem of 'ignorance' in philosophy and science, particularly with respect to the conceptualization, study and solution of environmental problems. We begin by distinguishing between 'risk', 'uncertainty' and 'ignorance'. We then offer a categorization of ignorance, and use these categories to assess the role of science as a means of reducing ignorance. We note that to proceed with science, several 'acts of faith' are necessary. We conclude with a discussion of the importance of an attitude of openness in science and philosophy, especially regarding environmental problems. Throughout, we illustrate our discussion of ignorance, and the problems involved in its reduction, by reference to environmental issues.

KEYWORDS: Environment, ignorance, openness, surprise

1. INTRODUCTION

The following paper offers an analysis of surprise and ignorance, in the context of environmental issues. Now it seems to us unfeasible to develop "a general tool for the operationalization of ignorance" (Funtowicz and Ravetz, 1990, 7) particularly for the area of environmental problems. In contrast to this endeavour, we feel that the first task has to be to recognize the whole range of human ignorance. In order truly to understand this ignorance we cannot confine ourselves to the field of environmental questions; rather we attempt to develop a general taxonomy of ignorance and surprise. This will lead us to a high level of abstraction, well beyond any particular problems. Hence the following considerations are widely philosophical, and seemingly far away from environmental issues. However, we feel that a deepened understanding of ignorance will be helpful in gaining a new attitude towards environmental problems; an attitude of openness and flexibility instead of an attitude of control and

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inflexibility.

From the origins of modern science the problem of knowledge and ignorance has long been recognised, especially by Kant. Two hundred years ago he saw the following as fundamental questions of philosophy:

> What can I know? What shall I do? What may I hope? (Kant, p.677, B833, our translation).

Especially important for scientists in general, and ecologically orientated scientists in particular, is the question: 'What can I know?'. The answer to this question is the basis for the questions: 'What can we control? What possibilities of action do we have? What can we do?' In the search for control of the natural world and protection against environmental damage we usually concentrate on these latter questions. Conversely, the question "What can I know?" has all too often been ignored by modern science. Hayek (1972, 33, our translation) pointed out:

> Perhaps it is only natural that the circumstances which limit our factual knowledge and the limits which thereby result for the application of our theoretical knowledge are rather unnoticed in the exuberance, which has been brought about by the successful progress of science. However, it is high time that we took our ignorance more seriously.

The extent to which it is necessary to follow Hayek's advice can be seen by considering the usual attempt to solve environmental problems. When we meet such problems we are initially ignorant as to how to solve them. Our almost invariable assumption, however, is that this ignorance can, by learning and by scientific exploration, be reduced or even completely eliminated. The outcome of this process is to turn what was initially a problem, through scientific and technological endeavour, into a solution. The presupposition for this approach is that human knowledge can be increased without limit in any given area, giving us a better and better understanding of how the world works. This increase in our understanding will therefore cause us to face fewer and fewer 'surprises' as our science develops.

By their nature, environmental problems are often global and long-run. As such, very often they involve the emergence of unpredictable events (novelty). There is, also, the possibility that they involve dynamic systems which exhibit infinite sensitivity to their boundary conditions (i.e. 'chaotic' systems [Faber and Proops, 1990, chapter 6]). This implies that the simple sequence of problem → science →technique →solution is not necessarily valid. On the contrary, we experience that our increasing knowledge may even impede the investigation for solutions. As Smithson (1989, 3) states:

> We are in the midst of an ignorance explosion in the well known sense that even specialists are inundated with information pertinent to their own fields. Likewise, the

> sheer number of specializations has mushroomed, as has the complexity of most of them.

We assert, therefore, that the simple structure of problem/solution, based on the faith that knowledge in any area can be increased without limit, and surprise be correspondingly reduced, cannot be valid for science in general. In particular, we believe it to be untrue for problems of long-run economy-environment interactions. Therefore, in this paper we take an approach which concentrates on ‘unknowledge’ and surprise, rather than on knowledge and fulfilled expectations. An improved understanding of ignorance and novelty may offer the basis for a more appropriate attitude towards environmental issues. There has already been considerable research about ignorance:

> The last 40 years, however, and especially the last two decades, have seen a flurry of new perspectives on uncertainty and ignorance whose magnitude arguably eclipses anything since the decade of 1660 which saw the emergence of modern probability theory (Smithson, 1988, 3).[1]

Also, a stimulating taxonomy of some aspects of ignorance in the area of society has been given by Smithson (1988, 9). While in this paper we develop a new taxonomy of surprise and ignorance, this includes no criticism concerning attempts like those made by, inter alia, Funtowicz and Ravetz (1991), Perrings (1991), Ravetz (1986) and Smithson (1989). However, the emphasis of our endeavour is different from these authors.

Section 2 deals with ignorance, surprise and novelty in our everyday life. In Section 3 we begin to analyze ‘ignorance’. Ignorance is first decomposed into ‘closed’ ignorance and ‘open’ ignorance (Section 3.1). Open ignorance is further subdivided into ‘reducible’ ignorance (Section 4) and ‘irreducible’ ignorance (Section 5). Reducible ignorance can be understood either as ‘personal’ ignorance (Section 4.1) or as ‘common’ ignorance (Section 4.2). Irreducible ignorance has either a phenomenological (Section 5.1) or an epistemological source (Section 5.2). Phenomenological sources of certain ignorance spring from ‘genotypic’ change (Section 5.1.1) or from the ‘chaotic’ behaviour of certain dynamic systems (Section 5.1.2). Epistemological ignorance is discussed in Section 5.2. It is subdivided into three further categories: ‘hermeneutic’ ignorance (Section 5.2.1), ‘axiomatic’ ignorance (Section 5.2.2), and ‘logical’ ignorance (Section 5.2.3). Following the discussion of ‘Pure’ ignorance and ‘uncertain’ ignorance in Section 6, an overview of all sources of surprise and ignorance is given in Section 7. In Section 8 we discuss the role of science in seeking to reduce uncertain ignorance to risk. In particular, we discuss the ‘acts of faith’ necessary in physical, social, and biological science. In Section 9 we draw conclusions from our findings for the study of environmental issues. In Section 10 we note that philosophers have often demanded an attitude of openness because human beings are inherently ignorant.

2. THE FUTURE IN OUR EVERYDAY LIFE: IGNORANCE, SURPRISE AND NOVELTY

Before we proceed to develop a further classification of ignorance we turn our attention to the nature and sources of ignorance. In this paper we restrict our considerations of ignorance to our ignorance concerning present and future events. To this end we now move to a discussion of the nature of the 'future'.

A definition of the 'future' might be: 'Any time which is later than now'. However, by making this definition, we move our problem to that of the definition of 'time', which is by no means easy. As Augustine noted:

> What, then, is time? I know well enough what it is, provided that nobody asks me; but when I am asked what it is and try to explain it, I am baffled (Augustine, p. 264).

Therefore, instead of trying to analyse the abstract notion of the 'future', we shall concentrate on the more concrete notion of 'future events', as reflected in our everyday lives. Every day we ask ourselves the questions:

1. What is going to happen?

2. What shall we do?

These have in common that they both concern future events; i.e. events which have not yet occurred. These questions are different because the attitudes they are based on are different. The question 'what is going to happen?' is theoretical, and reflects a contemplative and passive attitude; the question 'what shall we do?' is practical or ethical, and reflects an attitude of activity and intervention[2].

Of course, in everyday life these questions, and their corresponding attitudes, are interrelated. The answer to the first question provides a basis for answering the second question. For example, if a farmer 'knows' what the weather pattern will be like during the growing season, then he can 'know' what will be the 'best' course of action regarding planting, weed control, harvesting, etc.

On the other hand, in the course of time interventions taken on the basis of answers to the second question, 'what can we do?', may alter the circumstances in such a way that the answer to the first question, 'what is going to happen?', will itself be changed. For example, in many parts of the world, hilly countryside can only be cultivated in the long-run by contour ploughing. If the farmer chooses *not* to use contour ploughing, then the result will be soil loss and, eventually, the loss of the option of cultivation at all.

In earlier times. most predictions about future events, soothsayers apart, were experientially based (e.g. the weather lore of farmers). However, over the past two hundred years the rise of western science has given experiential regularities some conceptual underpinnings, often expressed as 'Laws of Nature' (e.g. Newton's laws of motion, the laws of thermodynamics, etc.). This has been immensely important in extending the range of prediction possible. We feel it has also been a source of misapprehension regarding the potential for knowledge about the future, as such theory allows prediction outside the range of experienced events. This may lead to the mistaken notion that, with sufficient theory, anything and everything may be predicted. Why this notion is mistaken is the major topic of the rest of this paper (see also Faber and Proops 1990, chapters 2-5).

2.1 *Surprise: examples and categories*

In our everyday lives, in our scientific endeavours, and in our attempts to control our social and natural environment, we are continually being surprised. We climb into our brand new car, turn the ignition key, and it refuses to start. We build a 'safe' chemical factory and it explodes.

Of course, not all surprises are unpleasant ones. We meet a stranger, and develop a deep and long-lasting relationship; we discover oil beneath the North Sea.

Regarding how we may be surprised, economists often follow Knight (1921) in distinguishing between 'risk' and 'uncertainty', as mentioned above in Section 2. (A similar distinction was made by Keynes (1921)). To this classification we wish to add the third category, 'ignorance', which in the literature, particularly of conventional economics, is not given the attention we feel it deserves. The main focus of our analysis in this paper will be on this category of ignorance.[3]

We can illustrate the distinction between these three categories (risk, uncertainty and ignorance) with an example of horse racing; in addition we will give an example from the field of environmental problems.

A keen follower of horse racing may frequently visit the track to bet on the outcome of the horse races. Such an individual will, when placing the bet on any race, have two facts in mind. First, what the expected possible outcomes could be: any horse in the race could win. Second, associated with each possible outcome is a subjective probability of the outcome actually occurring. It is this subjective assessment of probabilities, perhaps aided by close study of the racing form of each horse, that determines how the individual will bet. Here the individual can specify all of the anticipated outcomes, and associate probability of occurrence with each of them. This is what an economist means by 'risk'.

To illustrate the meaning of 'uncertainty', we might suppose that our keen follower of racing form need not also be a student of weather and its forecasting. Such an individual may accept that, from time to time, inclement weather may cause the racing to be abandoned altogether. Thus the outcome 'no racing' may be recognized, but not have associated with it a subjective probability.

Thus we see that our visitor to the race course might be surprised in two ways. First, the horse that wins may not be the one expected by that individual. Second, the race may not take place at all because the weather does not permit it, even though this was recognized as a possible outcome.

However, a visit to a race course might produce an even greater degree of surprise than either of the two above cases. The individual might arrive at the race course after an absence of a few months, to find the course has been redeveloped as a shopping mall. This outcome was one which had never even occurred to our racegoer, let alone been an outcome with which a probability had been associated. Shackle termed such an outcome an “unexpected event” (Shackle, 1955, 57) and characterized it as follows:

> What actually happens can have altogether escaped his (the individual’s, the author’s) survey of possibilities, so that the degree of potential surprise he assigned to it was neither zero nor greater than zero, but was non-existent, a sheer blank (Shackle, 1955, 58).

This inability even to specify all possible future outcomes we term ‘ignorance’.

For environmental issues we illustrate risk, uncertainty and ignorance with our second example. Let us consider the of use chlorofluorocarbons in refrigeration and manufacturing techniques. In this case, risk consists in the expected effects of this innovation, including possible side effects based on experiments. So firms involved may make probabilistic judgements on, for example, market penetration, the value of refrigerator sales, and the sales of frozen foods. The main environmental issue considered under this category would be food quality and its preservation.

Uncertainty may spring from several sources. Thus the possibility may be recognised that alternative food preservation technologies may be invented and innovated (such as freeze drying or radiation techniques); further legislation/taxation may change in an unforeseeable way the conditions of the market for refrigerators. Also, the uncertain probability of deleterious environmental side-effects may be recognised, such as the potential problem of the disposal of discarded refrigerators. Such possibilities may be seen, but not be associated with subjective probabilities. If these possibilities occur, they already will offer surprise to a great extent.

But the highest degree of surprise will be achieved when we discover, to our horror, that the ozone layer has developed a ‘hole’, and that this effect was caused as an unforeseeable side effect of our innovation of the use of chlorofluorocarbons in refrigeration. This consequence was completely outside the range of possibilities when we surveyed the possible consequences of our innovation. Until the moment the ozone hole was recognized as an effect of the use of chlorofluorocarbons, we had been in a state of ignorance.

It may be worthwhile for clarification to point out how the concept of ignorance used in the literature differs from ours. To this end we refer to an illustration given by Katzner (1986, 61):

> Now let a question be asked of such a kind that the individual is in ignorance of the possible answer that might be given to it. For example the question might be, ‘What

> kind of personal computers will be available for purchase two years from now?' One cannot have knowledge of answers to this question because there is no way of knowing what the future will bring. The set of possible outcomes (answers) cannot be known …

For this kind of literature it is typical that at least the area in which ignorance may occur is within the range of knowledge of the individual. Thus, in Katzner's example, although one is ignorant about the set of possible outcomes, one knows for sure that the outcomes will be personal computers. This kind of confinement is to be found in almost all of the literature on ignorance. We admit that this kind of approach is helpful and therefore we will employ it ourselves. In addition to this approach, however, one focus of our attention lies on those kinds of ignorance which do not pertain to a particular area of occurrences. Such kinds of ignorance are of particular importance for environmental problems, because the complexity in ecological systems is so encompassing that the drawing of any boundaries, or separation of distinct areas, would avoid the recognition of the true scope of our ignorance.

3. IGNORANCE

In this section we turn our attention to ignorance, and how it might be analyzed and classified.

3.1. *Closed ignorance and open ignorance*

Here it may be worth giving a diagrammatic representation of the classification thus far, as shown in Figure 1.

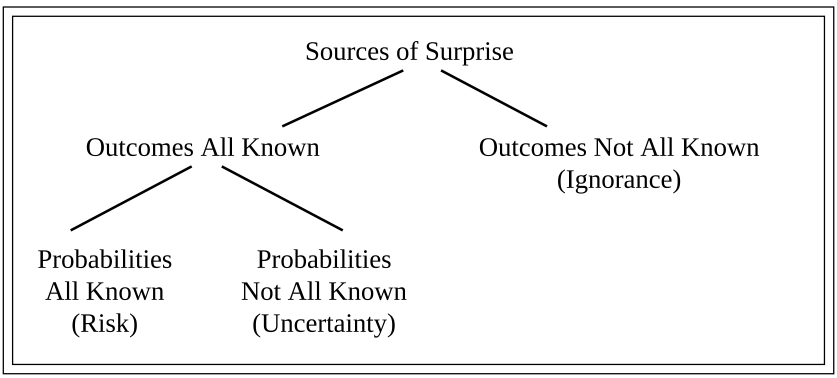

FIGURE 1.
Sources of Surprise.

From Figure 1 we note the crucial distinction between risk/uncertainty and ignorance, as we define them, is that the former pair are applied only in situations where all possible future outcomes can be specified, while the latter is applied where possible outcomes may not all be recognised prior to their occurrence,[4] or where even the area of possible outcomes may not be known in advance. Before we proceed we wish to distinguish between two main kinds of ignorance.

(1) We are often not aware of our ignorance, and therefore we feel no need for learning or research. Indeed, we may purposely ignore or suppress our recognition of our ignorance. We call this kind of ignorance ‘closed ignorance’. Closed ignorance may either spring from the unawareness of unexpected events, or from false knowledge[5] or false judgements. The condition of closed ignorance characterizes precisely the typical victim of the Socratic ‘elenchus’ (the Socratic mode of eliciting truth by short question and answer), as described in Plato’s earlier dialogues (e.g. Meno). Indeed, the Socratic elenchus is supposed to serve precisely the purpose of converting someone from the condition of closed ignorance to that of open ignorance.

As long as an individual remains in a state of closed ignorance s/he is unable to recognise that state; only if some event forces the experience of surprise, or if another person is able to make the individual aware of its state can the individual experience, ex post, the previous state of closed ignorance. However, very often individuals (e.g. politicians, scientists, etc.), social groups, or even whole societies, suppress the possibility of surprise and are not open to criticism. Thus they remain unaware of their state of closed ignorance.

It is important to note that very many social phenomena of ignorance occur in the area of closed ignorance; such ignorance may even be created by social processes. That is the reason why Smithson (1989, 216-263) studies this matter so extensively.

Closed ignorance, particularly in the form of pretended knowledge, is a great barrier to human cognition and insight, as well as to the solution of environmental problems. Thus closed ignorance concerning environmental issues means that we either neglect the problems themselves, or do not take notice of intuitive insights, experience, information, models and methods of solution which are available within society. An example of closed ignorance is the reaction of the Trojan society against Cassandra. Another prominent example of closed ignorance within the tradition of Western science is the attitude of Aristotelian scientists towards Galileo in the 17th century. As a last illustration of closed ignorance we mention the attitude of many scientists, engineers and politicians towards the risks of nuclear power before the accidents at Seven Mile Island and Chernobyl. Now closed ignorance is the determined non-recognition of ignorance, and it may be reflected by authoritative statements which cannot be literally true. For example, the assertion of low probabilities of melt-down by a nuclear reactor, prior to the two above events, is a statement of that sort. It is a mask of authority behind which ignorance may lurk.

(2) If individuals (group, societies) become aware of their previous state of closed ignorance (forced by drastic events, or guided by a changed attitude), they reach a state of ‘open ignorance’. In this state one will become attentive, e.g. of events and information, etc., which one had neglected earlier. Only in a state of open ignorance is one able to experience surprise to its full extent, and to react to it adequately. Of course, in a state of open ignorance one will try to understand surprising events by learning and research. However, one is not only aware that one may generate new surprises by research and learning, but knows that one remains, in spite of one’s increased knowledge, essentially in a state of ignorance. This is in line with the general tenet: ‘The more I know, the more I know I don’t know’.

Concerning environmental issues, a considerable shift from closed to open ignorance can be recognized in some present societies. Some decades ago, few were ready to acknowledge such problems; the environmental movement in some societies has forced this realization upon them. In particular, we view the rise of ‘green’ politics and ‘green consciousness’ as, at least in part, reflecting this attitude of greater openness to our ignorance. The present moves to reduce $C0_2$ emissions *before* there is unequivocal evidence of global warming (the ‘precautionary principle’) is further evidence of a more open view of our ignorance. We are beginning to realize that we, as a race, understand environmental problems only very incompletely, and that we are to a great extent ignorant about their range and their solutions. So perhaps we are now in a position where we gradually begin to turn from closed ignorance to open ignorance, at least concerning some environmental issues.

In Sections 4, 5 and 6 we turn to open ignorance. There we wish to distinguish two further types of ignorance, which we shall call ‘reducible’ ignorance and ‘irreducible’ ignorance. We represent this classification in Figure 2.

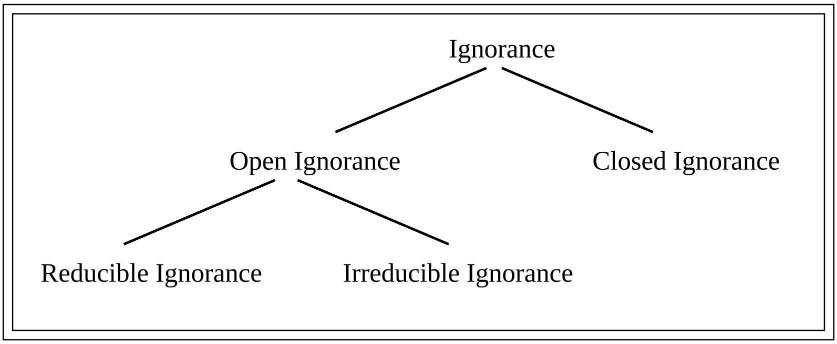

FIGURE 2.
A Classification of Ignorance.

If our ignorance is such that we cannot even classify it into one or other of these categories, we refer to it as either ‘pure’ ignorance or ‘uncertain’ ignorance. We return to this distinction in Section 6 below.

4. REDUCIBLE IGNORANCE

By reducible ignorance we mean ignorance which may be lessened, or even eliminated. We see reducible ignorance as falling into two further categories. First, ignorance that is personal; that is, the information is available within the society, but not to a particular individual. (Though this should not be taken to imply that one individual could encompass all of a society’s knowledge, or even all that of one area, e.g. physics). Second, there is communal ignorance, where the information is not even available to the society. We represent this classification of reducible ignorance in Figure 3.

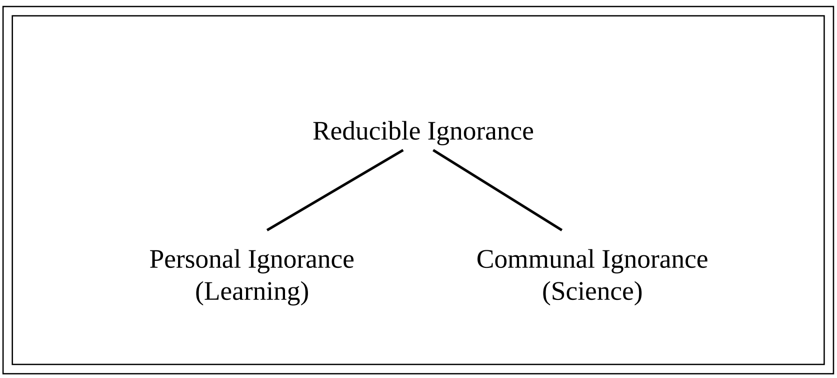

FIGURE 3.
Categories of Reducible Ignorance

4.1 *Personal ignorance and learning*

One reason we may be surprised at the occurrence of an unanticipated outcome is that we have simply been inefficient in the use of information which is available to us. For example, the racegoer who was amazed to find the race track no longer existed had only himself to blame for not reading the local papers, or speaking to other race track afficionados. In this case the ignorance that existed was avoidable, and with effort it was reducible.

Similarly, persons who suffer lead poisoning from household pipes could have avoided their sickness if they had used available information about this matter. In this case the responsibility for ignorance may either be attached to the individual, who did not sufficiently strive for knowledge in this area, or to the society (e.g. media, institutions) which did not take sufficient efforts to supply the individuals with the appropriate information. This kind of reducible ignorance we term ‘personal’ ignorance. We can reduce personal ignorance by obtaining information that is already available in the society, i.e. by individual learning.

4.2 *Communal ignorance and science*

Although many forms of ignorance that exist in society must be seen as ‘closed ignorance’, whereas other forms have to be addressed as ‘irreducible ignorance’, there is still another kind of ignorance, which we shall call ‘communal ignorance’. It is related to the ‘communal’ knowledge of a society.

There are many phenomena in the world which we, as a society, do not understand fully. In the case of some of them we are, more or less, confident that we shall understand them more fully in due course, through scientific exploration. To take an example from history, the causes of malaria were unknown until recently. But the suspicion that it was transmitted by mosquitoes, rather than by ‘noxious air’, was an hypothesis amenable to testing. The success of this hypothesis lead, in turn, to a search for the infecting organism in the blood of afflicted individuals. Thus the society’s initial ignorance as to the cause of malaria was reduced by the application of science. This kind of reducible ignorance of society is what we call ‘communal ignorance’.

Communal ignorance is always generated at the edge of the knowledge of a society. As long as we do not know for sure that our ignorance has to be interpreted as irreducible, we are to a certain degree entitled to hope that it will turn out to be reducible. In this sense, ignorance is a stimulus for all scientific endeavours, as long as we can surmise that this ignorance will be found to be communal ignorance. Thus all money spent for scientific research in society is spent on the presupposition that there is reducible communal ignorance.

Up to now we have dealt with kinds of ignorance which are already well-known in the literature. We now turn to areas of ignorance which have been studied less.

5. IRREDUCIBLE IGNORANCE

As well as ignorance which may be reduced by the accumulation and analysis of information, we wish to suggest that certain types of ignorance are in principle irreducible, i.e they cannot be reduced. We wish to distinguish two broad categories of irreducible ignorance. The first of these relates to the phenomena, and the second to the structure of knowledge. We term these ‘phenomenological’ ignorance and ‘epistemological’ ignorance.[6]

These categories of irreducible ignorance can be further subdivided. Phenomenological ignorance may be subdivided into 'genotypic' change (the emergence of novelty), and 'chaotic' dynamics.

Epistemological ignorance may also be divided into finer categories. These are 'hermeneutic' ignorance, 'axiomatic' ignorance, and 'logical' ignorance. We can represent this classification of the types of irreducible ignorance in

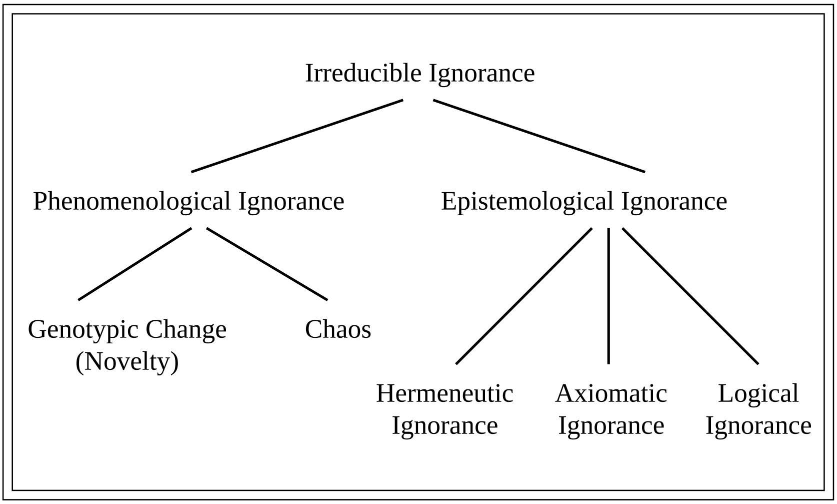

Figure 4.

FIGURE 4.
Categories of Irreducible Ignorance

5.1 *Phenomenological ignorance*

We begin by considering the category of phenomenological ignorance, where the nature of the phenomena makes our ignorance about these phenomena irreducible in practice. We begin with the emergence of novelty through genotypic change.

5.1.1 *The emergence of novelty: genotypic change*

A distinction we find useful for discussing how systems change over time is that between a system's 'potentialities', and its 'realisation'. In a biological system the potentialities are given by its genetic material or 'genotype'. These potentialities may be realised to a greater or lesser extent through the development of the, say, organism in interaction with its environment. In biological systems this realisation is known as the 'phenotype'. The realisations of an economic system would be the quantities of goods produced and consumed, the corresponding set of prices, the distribution of income, etc. Hence these descriptions would represent the economic phenotype.

The potentialities of an economic system are based on human attitudes and structures of social behaviour and structures of production. These potentialities can be recognized from the world view of a society (cf. Faber and Proops 1990, 87-94, 102-104), in particular from their religion or ideology. It can be further derived from the wishes, desires and preferences of the individuals, from the manners, norms and legal structures, as well as from the technological knowledge. In biology many genotypes can be described by means of genetic codes; but this description has been known for only some decades, while the concept of a genotype has been known for much longer, and has proved to have been of great explanatory relevance. In economics we are still in a situation similar to biology before the genetic code was developed. The economic genotype therefore cannot be described precisely.

In a certain sense, our knowledge about economics concerns only the economic phenotype, whereas the economic genotype is itself unknown, and can only be recognized by the phenomena it brings about. This ignorance about the economic genotype is not of much relevance as long as we can assume that the economic genotype does not change. In such cases ignorance does not pose a problem, since for a given set of potentialities the realisation of these potentialities will have a certain dynamics, which generally one could understand from knowledge of the potentialities. That is, we would normally expect to be able to understand the dynamics of the phenotype given knowledge of the genotype. Hence, even if the genotype is unknown, but does not change, there exists the possibility of predicting the phenotype (for a fuller discussion see Faber and Proops, 1990, chapters 2 and 3).

Ignorance of such systems may occur when the genotype itself changes, i.e. when the potentialities of the system alter. In biological systems such genotypic evolution is recognized as part of Darwinian evolution and the changes that occur in the system's nature will inevitably generate 'surprise'. Thus the long-run evolution of ecosystems may exhibit the emergence of novelty, and hence be unpredictable. Such evolution of the potentialities of systems is an irreducible source of ignorance.

Regarding environmental issues, these largely result from long-run economy-environment interactions. Now both ecosystems and economies can exhibit the emergence of novelty through genotypic change, so the possibility for the emergence of novel environmental problems (and perhaps solutions) is considerable.

5.1.2 *Deterministic dynamics and chaos*

The 'classical' concept of deterministic dynamical systems was summarized by Laplace who said, in essence, "Tell me the position and velocity of all the particles in the universe, and I can calculate all future states of the world". Here the notion is that if a dynamical system is deterministic, it is, at least in principle, calculable for all future states. The assumption Laplace made is that if the genotype of a dynamical system is fully specified and also unchanging, then the phenotype can always be completely determined.

Of course, one must recognize that any actual calculation can only be performed using a finite number of arithmetic operations. Therefore the principle of the computability of a phenotype from a completely known genotype requires that the future dynamics of such systems are calculable to any required degree of accuracy. One of the startling findings of recent mathematics, though one can trace the roots of this approach back to Poincaré, is that certain dynamical systems do not give better approximations the greater is the degree of arithmetic accuracy used (Lorenz, 1963; an excellent popular discussion is given by Gleick, 1988). Such systems, known as 'chaotic' systems, have an infinite sensitivity to the initial conditions imposed. The slightest deviation from the intended starting point generates a dynamical outcome which is entirely uncorrelated with the desired outcome.

Such systems are clearly a further source of irreducible ignorance. We may know everything there is to know about the determinants of such a system's behaviour, but still be quite incapable, in principle, of calculating even a 'reasonable' approximation to the system's dynamics. Thus even if a system's potentialities are fully specified and unchanging, it may be in principle impossible to determine the evolution of the realization of those potentialities. It may be the case that many economy-ecosystems interactions exhibit interrelations so complex that they are, at least in some aspects, chaotic in their dynamics, and hence in principle unpredictable. This is clearly another irreducible source of ignorance regarding environmental issues.

5.2 *Epistemological ignorance*

Irreducible ignorance need not come only from the phenomena, but may also come from the way we conceive the phenomena. Such ignorance we term 'epistemological' ignorance. We distinguish three kinds of such ignorance: 'hermeneutic' ignorance, 'axiomatic' ignorance, and 'logical' ignorance.

5.2.1 *Hermeneutic ignorance*

Even if a science is based on mathematical reasoning, it has to use words of the common language as soon as it is applied to phenomena. The general consensus of recent philosophy has been to suggest that it is impossible to construct an ideal language which can escape the ambiguities of common language (cf Wittgenstein, 1971, especially pp.63-81; Stegmüller, 1969, 397-428, 562-568). So scientists have to accept that, despite their sharpest definitions, they have to use words and notions which are not completely unambiguous. From this it follows that scientific statements also can never be totally clear and unambiguous.

So we remain, in a certain way, ignorant even if we express our surest knowledge, because we cannot do away with the problems of ordinary language. This may be a reason why scientists so often do not understand each other, although their theories seem to be totally clear. Now, hermeneutics is the study of meaning and understanding, in this case as mediated by language. This ignorance, derived from the nature of language and communication, we therefore term hermeneutic ignorance.

5.2.2 *Axiomatic ignorance: falsifiability*

All scientific knowledge is based, explicitly or implicitly, on certain basic assumptions, or axioms. The ideal scientist can derive the entire corpus of his knowledge from such an axiomatic system. These axioms are a combination of the distillation of our experience of the world, and also a reflection of our beliefs about the nature of the world. Perhaps in physical science, experience may be the dominating influence, while it seems to us that in much modern economic analysis, the axioms are much more reflections of belief structures.

By their nature the axioms can never be shown, singly or collectively, to be 'true'. However, if the 'theorems' derived from the axioms are at odds with our experience, then the axioms, singly or collectively, may be judged to be 'false'. In that we can never know the truth of our axioms, unless they are shown to be false, we remain ignorant at a very fundamental level of our scientific endeavour. Popper stressed the impossibility of the proof of the truth of an axiomatic science, stressing instead that the most we can hope to achieve is the 'falsification' of our axiomatic assumptions. In addition, it is important to note that there are many statements which can neither be verified nor falsified. For instance Aristotle's axiom that all bodies that move tend to a state of rest contradicts Newton's law of inertia. But both axioms can neither be proved nor falsified. Another example is Kant's claim that the statement 'human will is free', as well as the opposite statement, 'human will is determined,' can neither be proved nor falsified. But in contrast to the modern scientific attitude, Kant did not consider it to be meaningless to deal with these kind of statements, because they have such on essential importance.

5.2.3 *Logical ignorance: Gödel's theorem*

In 1931 Gödel proved that any axiomatic system which generates a formal basis for arithmetical operations must allow at least one theorem that, within the proof structure allowed by the axioms, can neither be proved nor disproved. Thus Gödel's (1931) theorem shows that even a non-falsified axiomatic system remains a source of ignorance, irrespective of our attempts, or otherwise, at falsification.

Unfortunately, by its nature Gödel's theorem gives no indication of what type of theorems may be undecidable in this way. Since 1931 there has been speculation over what thus far unproved theorems in number theory might be undecidable, with Fermat's Last Theorem being often suggested as one of this type.

From Gödel's theorem we therefore now know that even closed logical systems are sources of ignorance, and this ignorance cannot in principle be reduced. That is, even a system of logic is a source of irreducible ignorance. One consequence is that all those sciences which are applied systems of mathematical logic, e.g. physics and economics, contain at least one theorem that cannot be proved.

5.2.4 *Epistemological ignorance and environmental issues*

We wish to suggest that epistemological ignorance presents problems for any analytical science. Problems of language, axiomatization and the incompleteness of logical systems, have consequences for any discipline using mathematics. Now many environmental issues are approached using mathematical modelling, so even this apparently well-founded method is a potential source of ignorance regarding environmental problems.

6. PURE IGNORANCE AND UNCERTAIN IGNORANCE

Before proceeding to summarize our taxonomy of surprise and ignorance, it is important to point out that this taxonomy is not complete.[7] We further require the distinction between 'pure' ignorance and 'uncertain' ignorance.

6.1 *Pure ignorance*

We take it to be a self-evident truth that the accumulation and testing of knowledge that informs human activity has a unitary characteristic. The nature of knowledge, and ignorance, that pertains to our scientific work is no different to that relevant to the way we make a cup of coffee, or buy our weekly groceries.

In Western civilizations our response to ignorance is generally the assumption that it is reducible by science. We assume that the scientific method and the abilities of humankind will eventually fill these gaps in our 'knowledge'. However, when we ask ourselves, in everyday life or in science, 'what is going to happen?', we do not know in which area surprises will turn up. Further, we are ignorant of what kind of surprises we will meet. Naturally in this state we do not know whether our ignorance is reducible or irreducible. From this it follows that the kind of ignorance cannot be specified. If this is the case, we speak of 'pure ignorance'. We see that pure ignorance has two aspects. First, it is not confined to a certain area of knowledge. Second, it does not concern any particular occurrence or relationship. It can be thought of as the *context* within which we hold whatever knowledge we have (or think we have).

This kind of ignorance is an essential element of human life, of which science is only a part. Ignorance in this sense cannot be classified within the taxonomy developed above. This is because pure ignorance is of an indefinite nature, like the future itself. It cannot be limited or constrained to any particular area of knowledge, as it encompasses all areas of life and development. Humankind has developed many styles of coping with and/or reflecting upon pure ignorance. Among these we see ritual behaviour, religion and artistic endeavour.

6.2 *Uncertain ignorance*

Only when we are in a state where we are able to constrain the question 'what is going to happen?' to a particular area of knowledge can we ask ourselves if our ignorance is of a reducible or irreducible type. Since we then recognize the possibility of classifying our ignorance (viz. reducible or irreducible ignorance), but cannot yet classify it, then in accordance with the literature we denote this 'uncertain' ignorance. We normally make the act of faith that our uncertain ignorance is reducible (viz. open to learning or scientific discovery). However, this can only be an act of faith. If it transpires that science can reduce our ignorance, then, after the fact, we may classify our ex-ignorance as reducible. Thus we see that the distinction between reducible and irreducible ignorance can only be made ex post. However, it is in principle impossible to classify ignorance as reducible while the ignorance remains. Thus if we feel unwilling to make this act of faith, and if we cannot satisfy ourselves that our ignorance is irreducible, then, until the ignorance is reduced, intellectual honesty should compel us to classify our ignorance as uncertain.

Uncertain ignorance is a doubly uncomfortable state, involving both uncertainty and ignorance. The success of modern science owes much to the circumstance that science promises to convert uncertain ignorance into knowledge.

It seems to us that the normal modern, scientific, response to the recognition of ignorance is initially to assume it is reducible, and further, that it is personal, and accessible to reduction by learning from already available information. When we encounter a new environmental problem we seek the advice of the experts. If the experts are also ignorant on this matter, we turn to a programme of scientific research.

An example of ignorance, which has remained up to now uncertain, is nuclear waste. When society decided to carry through the development of nuclear power it believed that nuclear waste disposal could be dealt with in much the same way as non-nuclear waste. This proved to be untrue. Experts were consulted, and they suggested a scientific research programme be established. We may remain convinced, despite great costs over long periods, that our ignorance is reducible. Another example is nuclear fusion, which has been promised imminently for forty years, and remains still unfeasible.

We are not suggesting that either area is an area of irreducible ignorance. However, as we recognise irreducible ignorance may occur, and as reducible ignorance can only be recognized when it ceases to be ignorance, the possibility of irreducibility must be accepted (though humankind seems to prefer to have faith otherwise).

6.3 *Conclusions concerning pure ignorance and uncertain ignorance*

Pure ignorance and uncertain ignorance have in common only that they are not suitable for being included in our taxonomy. But their statuses are completely distinct. If we are confronted with uncertain ignorance, we try to cope with it. First we attempt to classify it as reducible or irreducible ignorance. We expect that sooner or later we will be able to do this. If the ignorance is reducible, then we find this out through its amenability to scientific investigation. Even if our ignorance is for the time being irreducible, we at least hope, and in general even expect, that we will find some method to deal with it. From these considerations we recognize that the state of uncertain ignorance is of a transitional nature; it changes over the course of time. In contrast pure ignorance is of an unchanging nature over the course of time.

7. AN OVERVIEW OF THE SOURCES OF SURPRISE

We summarize our result so far in Figure 5.

8. THE NATURE OF SCIENTIFIC ENDEAVOUR

Our view is that the normal ‘human condition’ is characterized by pure ignorance. We are continually being surprised, and often our surprise derives not from risk or uncertainty, but from ignorance. That is, our surprise is not because things happen to which we attributed low probabilities, or for which we had no probabilities. Rather, our surprise derives from events taking place which were not foreseen as possible.

As we know, classical science has attempted to transform uncertain ignorance into systematically organized knowledge. Modern science has suggested a more modest approach. Science may be considered as the attempt to transform uncertain ignorance into risk (i.e. statements with stochastic properties).

Readers without a natural science background may expect that the aim of science is not the generation of statements with only stochastic properties, but

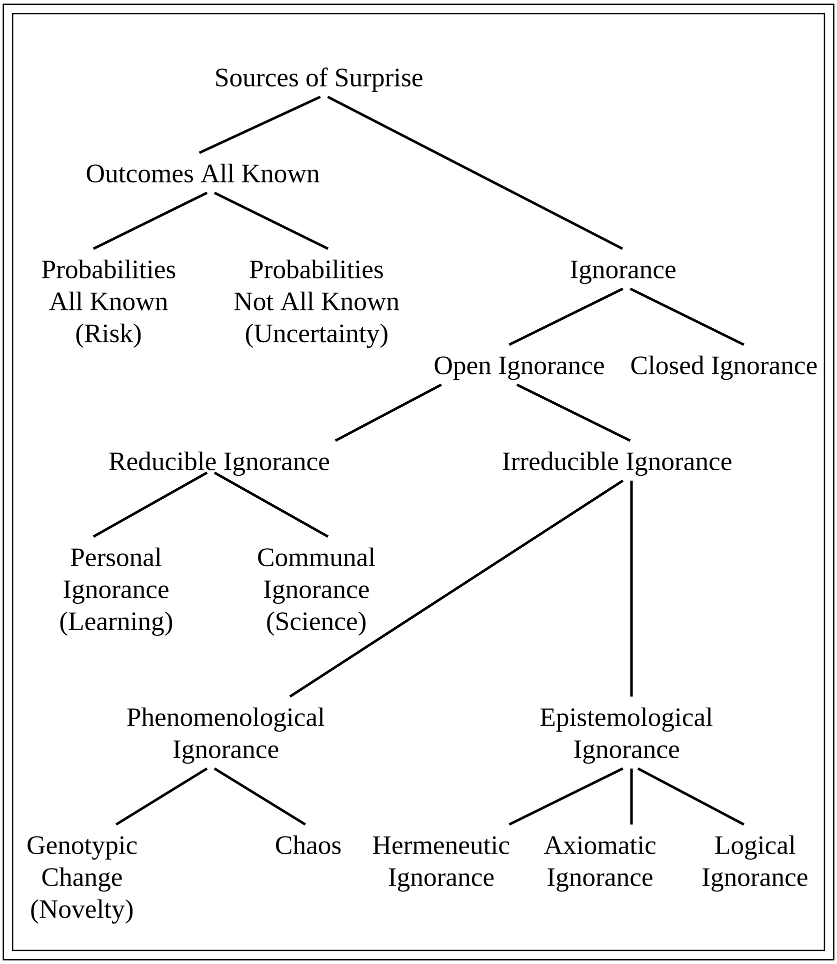

FIGURE 5.
A Taxonomy of Surprise and Ignorance

rather statements which are ‘true’, or perhaps ‘false’. This may be the aim; however, it is not feasible, by the nature of ‘noisy’ and error prone experimentation, and also, modern physics suggests, because of the inherent indeterminacy of the state of matter/energy. If our view of modern science is correct, then we can try to operationalize its way of dealing with ignorance as follows. If there are new phenomena which cause surprise, then one tries to get to know more and more about them, so that at the end of this endeavour all outcomes are known. In this case all the phenomena can be categorized under either risk or uncertainty.

If this endeavour is not successful, then scientists acknowledge their ignorance, but they tend to restrict this ignorance in terms of communal ignorance; i.e. they believe that further research will reduce and finally dissolve this ignorance. Thus we see the 'classical' route of modern science as being the transformation of uncertain ignorance into risk, as follows:

Uncertain Ignorance $\rightarrow$Communal Ignorance $\rightarrow$Risk

Hence, there is no concept of true irreducible ignorance in modern science.

We might represent the taxonomy of surprise inherent in science in Figure 6.

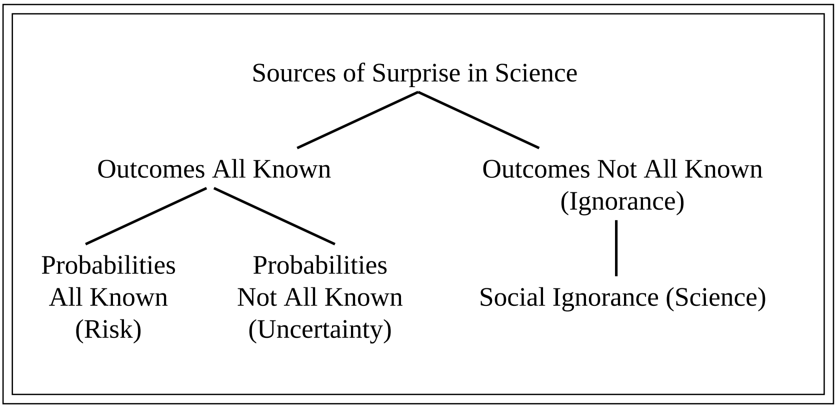

FIGURE 6.
Sources of Surprise in Science

Implicit within this scientific endeavour is the assumption that the object of scientific study is amenable to this reduction. This assumption cannot be testable, except in so far as it generates 'useful' and, perhaps, 'beautiful', science. Even so, this assumption is an axiom of science; that is, it is an act of faith.

8.1 *Physical science*

Regarding physical science, little in our experience argues against such faith in the 'reducibility' of uncertain ignorance to risk. However, modern mathematics has shown that what we have termed chaotic phenomenological ignorance is not only possible, but characterizes many important areas (Guckenheimer and Holmes 1983). This has demanded the recognition, in the practice of physical science, that knowing more about the nature of a system does not necessarily mean that statements about its behaviour can be reduced to statements which have the status of risk.

8.2 *Social science*

For economics, and the social sciences generally, the assumption that the systems being studied are amenable to statements with the status of risk seems much more questionable. The systems being studied are social systems, and the elements in these systems are humans whose natural condition is itself the confrontation of uncertain ignorance. It might be the case that over sufficiently short periods, and with sufficiently little ‘surprise’ affecting the social system being studied, then certain statements on aggregate social behaviour *may* be possible.

However, we view the above assumption that statements on social systems have the status of risk, which underlies social science, as inherently internally contradictory. On the one hand, humans as scientists explicitly recognise their uncertain ignorance through their scientific endeavours. On the other hand, the assumption made by scientists about humans is that there is no uncertain ignorance affecting the behaviour of the social agents whose behaviour they study. This seems to us like wanting to have your cake and eat it!

8.3 *Biological science*

The leap of faith needed for biological science seems to be somewhere between the relatively modest one of physical science, and the gigantic one of modern social science. For the study of microorganisms and the biochemical sub-systems of more complex organisms, the assumption that uncertain ignorance may be transformed into risk is probably generally acceptable. For studies of the behaviour of mammals the assumption may be as questionable as for social science. For ecological systems an additional major difficulty in their study is the introduction of novelty through human activity. (For a more detailed discussion on “why physics is easy, economics is difficult and biology is in between”, see Faber and Proops, 1990, chapter 3).

9. SURPRISE, IGNORANCE AND ENVIRONMENTAL ISSUES

We began with Kant’s question “What can I know?”. Our discussion suggests that one thing we *can* know is, to some extent, the nature of our ignorance, even if this is only knowing that we do not even *know* the nature of our ignorance.

How may this knowledge concerning our ignorance inform our behaviour? We have already noted that science is one of several methods of responding to the immanence of our uncertain ignorance. However, in this paper we have also defined and classified two other types of ignorance; phenomenological irreducible ignorance and epistemological irreducible ignorance. Regarding the former, modern science is itself discovering the limits to which uncertain ignorance may be reduced to risk, and the emergence of novelty. The discovery of the existence of chaotic dynamics has forced a somewhat startled recognition of these limits from the scientific community. Modern philosophy and mathematics also shows that there are epistemological constraints on the reduction of ignorance.

How might we respond, both as scientists in general, and as environmental scientists in particular? First, at a basic level, we feel that the nature of uncertain ignorance demands all that we can offer: recognition. We face uncertain ignorance in our ordinary lives, and recognise it at least implicitly. We also face it in our science, and explicit recognition in this sphere is also due.

Regarding epistemological irreducible ignorance, we know what the very nature of our understanding tells us we *cannot* know everything. The very structure of our rational scientific endeavour imposes limits on the achievements of that endeavour. Here we feel the appropriate response is humility. By this we mean, for example, that the scientific community should be modest concerning their own knowledge and their ability to contribute to the control of the world. Further, scientists should have respect for non-scientific approaches to the world, such as art and religion, as well as common-sense knowledge. Some traits of these ways may be integrated in the so-called ‘Second Order Sciences’ (Funtowicz and Ravetz, 1990). Other traits cannot be incorporated into a scientific approach. They remind the scientist of the fact that science is only one way for humans to experience the world (for a fuller discussion see Binswanger et al., 1990, and Faber et al., 1990).

Finally, phenomenological irreducible ignorance is an area where our recognition of our ignorance may be a key element in altering our behaviour. In a world where the altering potentialities of systems causes changes in those systems which may not, *in principle*, be predicted, our knowledge of that unpredictability may still be useful. If we know that changes in the nature of systems will occur, and we also know that we cannot know the nature of those changes until they occur, then the appropriate response is surely flexibility (for a fuller discussion of these ideas see Faber and Proops,1990, chapter 11 and Faber et al., 1990). For example, a non-flexible measure in the energy sector was the introduction of nuclear plants.

10. FROM IGNORANCE TO OPENNESS

That philosophy involves the study of knowledge is implied by its literal meaning, i.e. ‘love of wisdom’. But great philosophers of all periods have recognised that to understand knowledge one has also to understand ignorance. They realised that the region of our possible knowledge is like an island “surrounded by a wide and stormy ocean which is the actual site of semblance and illusion [Schein]” (Kant, B 295, our translation). This ocean of pretended knowledge is in truth the ocean of our ignorance. In the same vein Socrates said that "I know that I know nothing". This led the oracle of Delphi to acknowledge Socrates as the wisest of all human beings.

At the end of the middle ages one of the most important philosophers of that period, Nicolas of Cusa, postulated an attitude of 'Docta Ignorantia' (Book II, p. 93, paragraph 162). This meant the acknowledgment of the circumstance that all human knowledge emerges out of ignorance, and after some time may vanish or be replaced by new types of knowledge. For him the criteria for true science were adequacy to everyday experience, openness, creativity and flexibility. From this point of view he criticized, some decades before Copernicus, the geocentric world view of the ancient philosophers, with the argument that they lacked the 'Docta Ignorantia' or ignorance which is recognized and open to learning and alternative models. In our terms, this reflects their failure to recognize their axiomatic ignorance. As for pure ignorance, 'Docta Ignorantia' includes the faith that human thinking and action springs from a dimension which is greater than human knowledge, and which can be experienced only in humble acknowledgement of our ignorance.

One main intention of Kant's *Critique of Pure Reason* is expressed in the following sentence: "I had to eliminate knowledge to gain room for faith" (Kant, p.33, B XXX, our translation). Faith in the sense of Kant does not mean the adherence to any church or confession, but an attitude of openness and confidence towards all matters which lie in the area of our ignorance. Kant's ethics were offered as an attitude which is not only valid for known circumstances and tendencies, but also for the unknown.

The attitude of openness, as described by Plato, as well as by Nicolas of Cusa and Kant, can be seen as the essence of philosophy and knowledge. This attitude allows humans to experience all things as they develop, not as we might prejudge them, but accepting them as they are.

NOTES

We are grateful to Thomas Petersen, Alan Holland, Michael Hammond and an anonymous referee for their comments on earlier drafts.

[1] A detailed bibliography on ignorance and related subjects is to be found at the end of Smithson's (1988) monograph.
[2] It is interesting to note that the German construction for reference to future events, i.e. the future tense, uses the modal verb 'werden', the literal sense of which is 'to become, to grow'. On the other hand, the English future tense uses the verb 'to will', which, what native English speakers often forget, means 'to desire, to aim to bring about'. Clearly, the German future tense is based upon the first question, 'what is going to happen?', while the English future tense derives from the second question, 'what can we do?'.
[3] We recognise that the 'Bayesian' approach to probability and inference (Lee 1989) is an attempt to expand 'risk' into 'uncertainty', through the efficient use of information as it

becomes available. However, as we wish to concentrate on 'ignorance' in this paper, we do not pursue this matter here.

[4] Cf. the example of the personal computer given above by Katzner (1986).

[5] Construed in the same sense as one speaks of a 'false friend': something one has every reason to think is knowledge, but which turns out not to be so.

[6] Not all ignorance concerning phenomena or epistemological matters can be mapped as phenomenological or epistemological ignorance. Only those kinds of ignorance which are irreducible on the ground of the phenomena or on the ground of science are categorized as phenomenological or epistemological. Fallacy of our senses does not constitute phenomenological ignorance, nor do errors in our scientific approach constitute epistemological ignorance.

[7] We are grateful to Michael Hammond for pointing out this lacuna in our classification.

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