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Inferences Frequently Used in Earth Science

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Abstract: Various research methods have been used in science depending on the various contexts. This implies that certain methods or inferences may be more frequently used in earth science. The purposes of the study are to explore the contexts of earth science, and the inferences frequently used in earth science. The context of earth science research is quite different from that of other areas of natural science in terms of its time scale, space scale, accessibility, complexity, and controllability. The purpose of earth science research is twofold: historical and causal. The inferences frequently used in earth science are abduction and prediction. Abductive inferences go from the resulting state to controlling state. Predictive inferences go from hypothesis to expected data.

Key words: Earth science, philosophy of science, abductive inference, predictive inference

INTRODUCTION

The assertion that only limited number of unified science processes, such as the hypothetico-deductive approach, exist could not be supported any more by modern philosophers of science (Feyerabend, 1975). Mayer et al. (1992) suggested that this is misleading and the most far-reaching impacts of scientific investigation on our intellectual and cultural lives has been the result of investigations using historical and descriptive methodologies (p. 67). They also insisted that the hypothetico-deductive approach has been unable to provide adequate insight into the complex processes of the natural world. As various methods or inferences are used depending on the objectives and subjects of the research, certain methods or inferences may be more frequently used in earth science. Fortunately, there have been some efforts to figure out the characteristics of earth science in the area of history (Albritton, 1963; Laudan, 1987) and philosophy of earth science (Engelhardt & Zimmermann, 1982). Identifying methods or inferences in earth science is very important in order to understand the progress and nature of earth science, and provide strong foundation for effective earth science education.

The major purposes of this study are to explore the contexts of earth science, and to explore the inferences frequently used in earth science.

THE CONTEXTS OF EARTH SCIENCE INQUIRY

Thinking is closely interwoven with the context of the problem to be solved. The context includes the problem's physical and conceptual characteristics as well as the purpose of the activity and the social milieu in which it is embedded (Rogaff & Lave, 1984). The context of earth science research is discussed in terms of the goals of the earth science research, and the characteristics of earth science phenomena.

The Goals of Earth Science Research

The goals of earth science research can be categorized into two groups (Table 1); causal and historical (Laudan, 1987). Causal inquiry in earth science aims to establish general laws connecting causes and effects. The crucial entities of causal inquiry are "natural kinds"-that is, classes of objects with some nontrivial property or set of properties in common. They are distinct, timeless, and immutable. As an example, consider the geological kind "granite"

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Table 1. Comparison of causal and historical research in earth science

Goals of inquiry	Causal	Historical
Objectives	establish general laws connecting causes and effects	reconstruct a sequence of unique events
Entities	natural kind	formation
Results	laws or principles of earth science	chronicle

(Laudan, 1987). A granite in Seoul, Korea has similar properties with a granite in other parts of the world, in spite of the differences in the age of formation.

The other goal of earth science research is historical. The historical inquiry aims to reconstruct a sequence of unique events. The crucial entities of historical inquiry are unique historical events or the rocks that were formed during a particular time of period, ie., formations (Laudan, 1987). Each formation is unique because it is limited to a particular period of time, quite unlike a natural kind.

The Characteristics of Earth Science Phenomena

Earth science phenomena are characterized by several features, such as a large time and space scale, inaccessibility, uncontrollability, and complexity. These characteristics also form a unique context for earth science research.

The time scale of earth science is often vast. For example, geological events usually spans more than hundreds of thousands of years. The consequences of such a large time scale are as follows. The cause of a certain effect of interest often happened in the geologic past. Other times the effect of a cause of interest will occur in the future. Finally, earth scientists cannot observe such processes from the beginning to the end (Lee, Kim, & Choi, 1993).

The spatial scale of earth science phenomena is also often enormous. For example, the theory of plate tectonics deals with plates which are larger than continents. The large spatial scale consequently makes it difficult for earth scientists grasp the whole aspect of phenomena at a time (Lee, Kim, & Choi, 1993).

Earth science phenomena are often inaccessible to earth scientists (Engelhardt & Zimmermann, 1982). For example, many earth science phenomena resulted from submarine, subterranean changes. The structure of the deep zones of the Earth were studied without direct exploration of the Earth's interior (Laudan, 1987). Therefore, earth scientists frequently have to construct hypotheses with indirect evidence.

Fourth, it is hard to control the variables of earth science phenomena (Kim, 1995). For many kinds of natural phenomena in earth science, it is difficult to operate or control the variables involved. For example, earth scientists cannot make volcanoes or earthquakes but have to wait until they happen. As a consequence, they largely have to wait passively to observe eclipses or meteo showers without any possibility of reproducing, much less actively interfering with, such events.

Fifth, earth science phenomena are usually more complex than those of other areas. Earth science phenomena are the work of many causes that are often in highly complex interaction with one another. For example, the transformation of a region from ocean into continental land might well be considered as a single event. But it could be explained as a very complicated effect produced by an intricate sequence of operations conditioned at every stage by the cooperation of a variety of natural agencies (Laudan, 1987). The consequence of the complexity is that earth scientists have to depend upon many related theories.

Finally, earth scientists usually have to rely on a small portion of the evidence, because much potential evidence has been lost or removed by erosion or deformation. For example, earth scientists reconstruct dinosaurs skeletons with very limited number of bones found.

The characteristics of earth science phenomena discussed above make it very difficult for earth scientists collect data and understand the phenomena to be investigated. Therefore earth scientists may frequently rely on inferences which are different from those of other disciplines of science with different contexts.

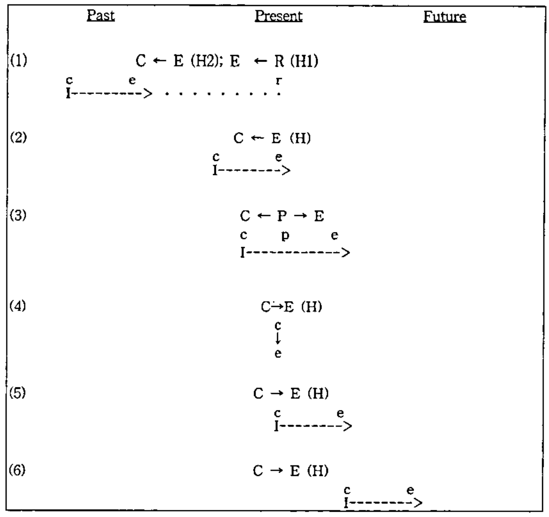
The Context of Earth Science and Inferences

To explore the inferences in earth science, six possible types of occurrence of cause and effect in earth science are developed and analyzed (Fig. 1). For the purpose of analysis, symbols are used, representing the controlling state of affairs as 'c' and the proposition describing it 'C'. The resulting state of affairs will be called 'e' and the proposition describing it, 'E'. The remnants of the resulting state at present is called 'r' and the proposition describing it 'R'. The on-going state of affairs will be called 'p', and the proposition describing it 'P'. H stands for hypotheses explaining underlying laws.

As earth science deals with such a large time scale, many phenomena occurred during a geologic time period, and only part of the effects remain at present as (1) in Fig. 1. Earth scientists have to observe and describe remaining effects first, and then they reconstruct the effect, and the resulting state R. Next, they try to find out the cause, controlling state by finding out the best hypothesis H. Some phenomena or event began during geologic time and has finished recently, hence most of the effect or resulting state remained as (2) in Fig. 1. Earth scientists may collect data, transforming the data into proposition E, and establish hypothesis H. These types, (1) and (2) in Fig. 1, could be often found in causal as well as historical research.

Sometimes phenomena began but the process is still not finished as (3) in Fig. 1. Earth scientists may observe some part of the process, and may have some understanding about the process making guesses based on limited experience with the phenomena. In this cause and effect type, only part of the on-going state is available to earth scientists. Therefore earth scientists may develop the best hypothesis about the cause or effect based on limited data on the processes and related theories.

If a phenomenon with short time scale is happening at present, the earth scientist may observe the whole



c: cause, C: proposition describing c, e: effect, E: proposition describing e, r: remnants of the past effect, R: proposition describing r, p: on-going state, P; proposition describing p, H: hypothesis explaining underlying relationship

Fig. 1. Possible types of inferences in earth science by time scale.

process and establish a hypothesis as (4) in Fig 1. The hypothesis might be a good source to provide possible candidates of explanation to earth science problems with similar conditions.

Recently earth scientists try to predict future conditions with the data of the past and present as (5) in Fig. 1. Global warming, and ozone problem are examples of this sort. Earth scientists usually develop models from recent patterns and data, and conduct simulating activities to predict future change. If these activities may be projected to the cause and effect of the future as (6) in Fig 1, earth scientists may deal with future problems about the earth, solar system, or the universe. In these types, the inference frequently used by earth scientists is prediction, usually going from the controlling state to resulting state in the future.

In addition to the large time scale discussed so far, other characteristics also affect the method or inference of earth science. Because of the large space scale and inaccessibility of earth science phenomena, earth scientists have to rely on partial, indirect evidence during research. Because of this large space scale and inaccessibility, only partial effects are available to earth scientists.

Earth scientists could not usually isolate and control variables, hence could not conduct controlled experiment. The complexity and very complicated history of phenomena of earth and space also contribute to the role of imagination and guess work in earth science compared to other disciplines of science. These factors prevent earth scientists from using the hypothetico-deductive approach. Based on the above argument, inferences frequently used in earth science seem to be abduction and prediction.

Abduction and Prediction

Abduction is a kind of inference proposed by Peirce (1878). Abduction is to infer a case from the result and the rule. For more clear understanding about abduction, three forms of inferences, induction, deduction, and abduction are explained and compared below. Deduction is drawing logical consequences from premises. In deductive inferences, the conclusion is true given the premises are true also. The logic and an example of deduction are as follows.

Deduction: Logic
(Rule) if p, then q
(Case) p is given

(Result) q must be the case

Deduction: Example
(Rule) Humans die
(Case) Socrates is human

(Result) Socrates dies

Inductive logic is based upon the notion that probability is the relative frequency in long run and a general law can be concluded based on numerous cases. The logic and an example are shown below.

Induction: Logic
(Case) A1, A2, A3 ... An are B
(Result) A1, A2, A3 ... An are C

(Rule) Therefore B is C

Induction: Example
(Case) Socrates is human
Aristotle is human
.....
(Result) Socrates dies
Aristotle dies
....

(Rule) Humans die

Abductive inference, going from the resulting state of affairs to the controlling state of affairs, must basically remain tenuous since in principle the same result can be produced by any number of premises (Engelhardt & Zimmermann, 1982). The logic and an example of abductive inferences are given below.

Abduction: Logic
(Result) q is given
(Rule) if p, then q (better than any other alternatives)

(Case) p may possibly be the case

Abduction: Example
(Result) Socrates dies
(Rule) Humans die

(Case) Socrates is human

Abductive inference becomes more certain when, instead of many possible controlling states of affairs, only a few states actually considered, some of which can moreover even be weighted as being either more or less plausible.

Examples of abductive inference in earth science are shown below. Earth scientists observe a mineral through polarizing microscope and find that the mineral is optically isotropic. As cubic crystals are optically isotropic, the mineral could be optically isotropic (Engelhardt & Zimmermann, 1982).

(1) Resulting statement

The crystallized mineral X, whose name is not yet known, is optically isotropic.

(2) Law

All crystals of cubic crystal system, and only these crystals, are optically isotropic.

(3) Controlling statement

Mineral X belongs to the cubic crystal system, that is the arrangement of atoms in its crystal lattice corresponds to the conditions of one of the cubic symmetry groups.

Abduction is similar to induction in that the truth of conclusions is not logically guaranteed. However, they differ in several aspects. Inductive inference proceeds from statements about known phenomena to general statements which resemble the known. Abduction involves a search for hypothetical conditions which are linked with suitable laws to describe exactly the state of affairs.

Abduction plays the role of generating new ideas or hypotheses; deduction functions as evaluating the hypotheses; and induction is justifying the hypothesis with empirical data.

Josephson and Josephson (1996) proposed that prediction is a inference. Usually predictions have traditionally been thought of as deductive inferences. However, predictions from hedged generalizations are not deductions because the conclusion may be false while the premise is true. Such an inference cannot possibly be deductive (Josephson & Josephson, 1996). An example of prediction is as follows.

Prediction: Logic

(Hedged generalization) *P* has high probability.

(Conclusion) Therefore, *P*.

Prediction: Example

(Hedged generalization) The chance of shower is 80% under these weather conditions.

(Conclusion) It is going to rain today.

According to Josephson & Josephson (1996), predictions are neither abductions nor deductions, but a new kind of inference. Predictions go from hypothesis to expected data while abductions go from data to explanatory hypotheses.

CONCLUSION

The major form of inference is explored based upon the context of earth science. The goals of earth science are twofold: causal and historical. Historical research in earth science usually uses abductive inference, because it always begins from the resulting state. The characteristics of earth science phenomena, such as time-scale, space-scale, accessibility, complexity, and controllability, mean earth scientists have no access to them, and thus they rely on partial, indirect evidence. Hence the causal inquiry also requires abductive inference. Recent concerns on global problems urge earth scientists use predictions as an inference. Therefore, abductions and predictions are major forms of inferences in earth science. Abductive inference, going from the resulting state of affairs to the controlling state of affairs, is logically tenuous but practically very powerful. Abductive and predictive inferences could be explored and be used for more effective earth science instruction.

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