"On-Line" Inductive Reasoning In Scientific Laboratories: What It Reveals About The Nature Of Induction and Scientific Discovery

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Abstract

"On-line" data of scientists thinking and reasoning in their laboratories were collected and analyzed, providing a rare glimpse into the day-to-day use of induction by scientists at work. Analyses reveal that scientists use different types of induction in specific orders and cycle through such types in ways that are dictated by their current goal and context. Further, the processes involved in major conceptual changes are identical to those involved in minor conceptual changes. Finally, first time analyses of women and men scientists reasoning in laboratories show that women and men scientists reason in a virtually identical manner.

New Approaches to Scientific Discovery

The goal of this research is to provide a model of how and when scientists use different types of induction, and under which circumstances one type of induction will be used rather than another. We have addressed these questions using two approaches. One approach is to investigate scientists as they reason "on-line" at weekly laboratory meetings (Dunbar 1995, 1996, 1997). Laboratory meetings provide a microcosm of the different types of thinking and reasoning strategies that scientists engage in. The meetings include reasoning about the design of experiments, theory, the interpretation of data, and contain occasional scientific discoveries. Using this novel approach, we have investigated scientists at two major universities in 4 molecular biology and 4 immunology laboratories. We have adapted techniques from protocol analysis, and used these techniques to analyze transcripts of scientists talking, and reasoning "on-line." We have been able to determine the types of reasoning that scientists engage in when they are formulating theories, designing experiments and interpreting data.

The second approach is to take real scientific problems, bring them into the cognitive laboratory, and put subjects in a similar state of knowledge as the scientists (e.g., Dunbar, 1993, Rapus & Dunbar 1997). In Rapus & Dunbar, we have taken the discovery of "Prions" --the putative cause of mad-cow disease-- into the psychological laboratory and investigated the conditions under which subjects will and will not discover Prions. The performance of the subjects is surprisingly similar to that of the scientists who discovered Prions (cf. Rhodes 1997) and to the scientists that we have been investigating. Thus, the real scientists and our laboratory investigations of scientific thinking are beginning to converge on a common set of mental operations and sequences of mental operations that are at the core of scientific thinking. In this symposium, I will focus on our analyses of induction in science.

"On-line" Induction in Science

Many analyses of induction have focused on its central role in science and, paradoxically, on the inherent limitations of using induction. The term induction has been used in two senses (Thagard in Press). First, induction has been used to describe any inference that involves uncertainty (i.e., inferences not based upon deduction). Second, induction has been used for specific types of inferences such as Analogy, Causal Reasoning, Generalization, and Categorization. Each of these types of induction has received an enormous amount of research.

Using transcriptions of over 50 hours of video and audiotaped laboratory meetings, we have analyzed, sentence by sentence, the types of inductions that scientists use. We first coded all instances of induction in the broad sense; any non-deductive form of reasoning. We then sub-divided all inductions into Classifications, Analogies, Causal Reasoning, and Generalizations. We also coded the goals of the scientists, types of findings that they were reasoning about, and other contextual information. We then grouped together the different types of inductions in terms of the scientists' goals and co-occurring types of reasoning.

These analyses reveal that induction is used in a number of different ways in scientific reasoning, depending on the context and goals. In *designing experiments*, scientists frequently use induction--particularly in the form of analogy--to pick specific designs and to formulate the precise conditions of experiments. This result is surprising, as many theorists have described experimental design as a mainly deductive process. *In reasoning about data*, the scientists use a number of different forms of induction, often in a serial manner. First, scientists attempt to classify results in terms of known concepts. The scientists attempt to classify their results and to link these classifications back to their experimental design. Often these classifications allow the scientists to determine whether their experiments were conducted correctly. Second, for any findings that are not immediately classifiable, usually unexpected findings, the scientists attempt to build a causal chain that will tie the findings to a known concept. This stage often involves making an analogy to a known concept in another related organism or domain. Third, if the scientists cannot account for their findings, either through simple classification or through analogy (the first two steps), they will then attempt to formulate a new concept. The new concepts tend to be generated either by taking common properties of their findings, or proposing a new concept based on features of one finding. The new concept can then serve as input to a new cycle of induction and evaluation as stated above in steps one to three.

These analyses reveal that induction takes place in a specific sequence starting with classification. Only when classification does not account for the data will scientists engage in more complex types of inductive processes such as analogy and generalization. This particular sequence of types of inductions is dynamic and can change as a function of the knowledge state and goals of the scientists. Furthermore, it is not uncommon for scientists to cycle through the types of induction when they obtain unusual findings .

Do scientists remember how they made a discovery? We have also found that much of the reasoning that we captured was not remembered by the scientists, and that interviews with the scientists, even two days after a meeting, or a discovery, revealed that the scientists had forgotten key components in their reasoning. The scientists were very surprised when they saw trancripts of what happened.

Induction and Conceptual Change

One important question that our data allow us to address is whether the processes that are involved in a minor change of a concept are different from those involved in a major change of a concept in which a new concept is generated and the old conceptual structure is reorganized. We have found that exactly the same types of induction occur in both major and minor conceptual changes. The only difference between major and minor conceptual change is that minor conceptual changes can be accomplished using a single type of inductive process working alone, such as generalization. However, major conceptual change involves many different types and cycles of induction. We have witnessed a number of major conceptual changes that involved the use of many different types of induction. Thus, there is not one magic step such as a generalization working alone that will produce major conceptual change. We have observed this in the real world and in our experiments. We have found that when given sets of findings about "mad cow disease" subjects will generate the concept of Prions when they use combinations of different types of induction such as analogy, classification and generalization (Rapus & Dunbar, 1997).

Are There Gender Differences in Inductive Reasoning?

Many scientists have argued that women scientists think differently from men scientists. This hypothesis is based largely upon surveys or retrospective reports and have pointed to ostensible differences in the use of induction by women and men. We have been extending our analyses of induction to address this issue by analyzing the types of inductive reasoning that women and men scientists engage in. Our analyses reveal that women and men scientists reason in exactly the same ways. The only difference that we have discovered is that women are somewhat more likely to generate new hypotheses in response to unexpected findings than men. We have found that women and men's use of specific types of inductions, such as classifications, analogies, or causal reasoning to be identical.

Conclusion

Overall, the results of our different investigations of induction are revealing a dynamic picture of the way that different types of induction are used in science. These analyses are making it possible both to build more detailed models of induction and to propose new ways of training future scientists (Dunbar, in press).

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