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## CHAPTER 1.

### INTRODUCTION

This thesis is about inductive learning. More particularly, it is about the difficulties associated with inductive learning. Research has shown that the (educational) gain of inductive learning is not as high (see for an overview De Jong & Van Joolingen, 1998) as initially claimed (Bruner, Goodnow, & Austin, 1956). The first question addressed in this thesis concerns this topic: "*Why is inductive learning less effective than claimed?*"

To answer this question, the related question: "*How to measure the quality of the inductive learning process?*" will also be addressed. This is necessary as inductive learning is difficult both for the "learners", the people submerged in inductive learning, as for the researchers studying inductive learning. For example, there is no generally approved variable that measures the quality of the inductive learning process.

The structure of this chapter is as follows. First, inductive learning is defined. Hereto, induction, as the process that is the basis of inductive learning, is contrasted to deduction, and inductive learning is contrasted to scientific discovery learning. Second, five reasons to study inductive learning as identified by Klahr and Simon (1999) are discussed, and related to the studies reported in this thesis. Finally, the four Chapters that each discuss a different aspect of inductive learning are introduced and discussed.

### INDUCTIVE LEARNING

In their influential book on induction, Holland, Holyoak, Nisbett, and Thagard (1986) define induction as "all inferential processes that take place in the face of uncertainty" (Holland et al., 1986, p.1). In other words, induction is concerned with inferring knowledge from an incomplete set of observations. The most typical way to infer knowledge is by inducing rules that hold for a complete domain, that is, also for the parts of the domain that are not directly observed. As the resulting knowledge is based on incomplete information, it is inherently uncertain because the not observed

parts of the total set of observations might falsify the inferred knowledge.

This contrasts induction with deduction where the learner formulates regularities observed in a (complete) set of data. Deduction does not produce knowledge that is semantically new. It does not go beyond the observations. In contrast, induction, in the words<sup>1</sup> of Johnson-Laird (1993) is: “any process of thought yielding a conclusion that increases the semantic information [that was available] in its initial observations or premises” (Johnson-Laird, 1993, p.60).

Another issue related to induction is how these observations are constructed. In most induction related tasks the learner has to engage in the discovery process without explicit guidance, i.e., the learner has responsibility for the construction of the data set (Anderson, 1995).

With the emphasis on the self-directed nature of inductive learning and the focus on inducing new rules for yet unobserved data, inductive learning is closely related to scientific discovery. Often, these two terms are used interchangeably. Whereas the terms induction and inductive learning are often referred to in the context of contrasting induction with deduction (but see also Poletiek, 2001), scientific discovery is the term most often used when this task is studied for understanding the underlying processes. The “scientific” part of this term implicitly emphasizes the importance of constructing and testing hypotheses (cf. the empirical cycle of De Groot, 1969, the often cited methodology underlying scientific discovery). In contrast, the term induction refers to the focus on gathering knowledge based on an evidence-driven instead of hypothesis-driven process. As discussed in later Chapters, learners in the tasks studied in this thesis seem to be less focused on central hypotheses. Therefore, in the remainder of this thesis, the term inductive learning will be preferred over scientific discovery. However, regardless of the name, the central issue is: Why study inductive discovery learning?

## WHY STUDY INDUCTIVE DISCOVERY LEARNING?

In an overview paper by Klahr and Simon (1999), five reasons for studying scientific discovery or inductive learning are identified:

**1. Human Value** By studying scientific discovery we might better understand the

<sup>1</sup>See Manktelow (1999) for an extensive overview of different views on induction

mechanisms of “scientific thinking [that] has enhanced our ability to understand, predict, and control the natural forces that shape our world” (p.524). This in itself is claimed by Klahr and Simon to be a viable reason to study scientific discovery processes.

2. **(Non-)Mythology** Although reports of scientific discovery are often surrounded with mythological explanations (from an apple that falls from a tree to the rising of the level of water in a bath), Klahr and Simon claim that “normal” cognitive processes are at the basis of most scientific discoveries. One of the aims of studying scientific discovery learning is to demystify the processes involved.
3. **Pressing the limits** Inherent to the nature of discoveries, most discoveries are related to examining the limits of the then-known theory of the domain under study. However, they are also taking place at the limits of the discoverer’s knowledge and/or reasoning capacities. Nevertheless, Klahr and Simon claim that the methods used to arrive at new discoveries are not fundamentally different from everyday thinking.
4. **Relation to Development** Research has shown that although children’s discovery behavior is not as sophisticated as adults’ behavior, children do show behavior that supports the notion of the “child-as-scientist”: actively engaging in a quest for explanations. As this behavior is not formally taught to young children, studying development in general and the development of discovery processes could yield more information about the underpinnings of scientific discovery. Moreover, when more is known about the nature and use of scientific discovery, applying this knowledge in educational settings could improve learning effectiveness.
5. **Computational Support for Scientific Discovery** By identifying the important processes of scientific discovery, computer programs can be designed on the basis of these processes to aid human scientific discovery. However, most of the current approaches in this field are mainly based on mathematical methods (e.g., inspecting deviations from correlational patterns) instead of methods based on knowledge about the human discovery processes. By learning more about the human discovery processes and implementing this new knowledge,

the supporting computer programs might become even more helpful discovery assistants.

Of these five reasons, the research reported in this thesis is mainly concerned with the reasons 2, 3 and 4<sup>2</sup>. As claimed by Klahr and Simon and reflected in their second and third reason, the assumption underlying the research in this thesis is that scientific discovery can be considered a relatively "normal" process, or at least one that can be carried out by humans that are not professionally trained researchers. This topic will be the main focus of Chapters 3, 4 and 5. Chapter 2 focusses on the development-related issue. Based on detailed empirical developmental data, this chapter gives an in-depth explanation for the development from imperfect knowledge to a final set of relations that accurately describes the given domain.

## STUDIES REPORTED IN THIS THESIS

In most of the studies discussed in this thesis, inductive learning is studied in controlled laboratory experiments. In such a laboratory setting, university students or younger children are presented with a (computer) simulation of a particular domain. By means of self-directed experimentation, they have to induce the rules underlying the domain.

In Chapter 2 we analyse development on the balance scale as inductive learning. In particular we give an explanation for well-established phenomena in development on this task. This model does not involve active experimentation because few experimental studies include this form of learning. Instead, empirical data is used that was gathered by presenting different age groups with a set of experimenter-controlled experiments. In contrast to the classic method of analyzing the inductive learning processes by correlating overt behavior phenomena with the outcomes of the learning process, Chapter 2 describes a computational model of the same task as presented to the learners. Based on an analysis of the differences observed between the age groups, and the transitions from each level of performance to a next, a computational model was constructed that accounts for the important aspects of performance. By analyzing this model, for example, through the identification of the mechanisms nec-

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<sup>2</sup>The first of these reasons is a relative or subjective criterion, that is, what intrigues one researcher, has no impact at all on another. The fifth reason is purely practical. As this thesis is involved with explaining discovery learning, the application of knowledge about the discovery process is outside the scope of this thesis.

essary to account for observed behavior, inferences can be made about the underlying processes in human learners. We will argue that the typical phases observed in children's behavior can be explained by assuming a simple problem-solving strategy and a gradual increase in available resources and knowledge.

A similar approach is taken in Chapter 3. On the basis of a rational analysis of a discovery task presented to college students and based on an analysis of their behavior, a family of computational models is constructed that is based on the influential Scientific Discovery as Dual Search theory (Klahr & Dunbar, 1988). By comparing the differences between models and the match of these models with data of certain learners, the relative importance of different aspects of the inductive learning process is assessed. This comparison shows that learners use appropriate discovery techniques and that scope of effects discovered is largely dependent on the learner's prior knowledge and assumptions.

In both Chapter 2 and 3, the assumptions underlying computational models are tested by comparing the behavior of the models with empirical data. A methodologically inspired stance is taken in Chapter 4. To construct a psychologically plausible computational model of an inductive learning task, detailed information has to be available about the underlying process and knowledge that guides performance. However, as in almost all psychology domains, these processes and knowledge are not readily available for observation. Therefore, particular aspects of overt behavior have been used as measures for assessing which mechanisms underly inductive learning. At the same time, measures such as the number of unique learning-instances created by a learner have been used to assess the quality of a learner's inductive learning skills. However, the computational modeling effort and task analysis presented in Chapter 3 shows that such measures are not necessarily indicative of the quality of the underlying processes. Chapter 4 proposes a measure that is based on an analysis of the subprocesses involved in inductive learning. It is argued that this measure better reflects the quality of the inductive learning process than existing measures.

Analyzing the behavior of a learner is directly related to the ease of categorizing the learner's behavior. In the tasks presented in Chapter 2, 3 and 4, as in most other published inductive learning tasks, this poses no problem as each action of a learner results in a new and distinct configuration of the experiment setting. However, in tasks that resemble real-life discovery situations, the values of variables are often

expressed on a continuous scale and modified in a continuous fashion - and therefore they are not as readily compared. Chapter 5 focuses on such a more complex task, Optics. As the important variables defining this task are indeed expressed on a continuous scale, one has to devise a method to analyze the continuous behavior. Chapter 5 introduces a qualitative reasoning model to analyze this type of discovery settings. We argue that the learners' behavior can be characterized as being based on simple strategies that are mediated by both prior knowledge and the saliency of the discrepancies between prior knowledge and observed behavior. This characterization also explains why learners often conduct insufficient experiments.

Although all chapters address both questions that were put forward at the start of this introduction, Chapter 3 and 5 are mainly concerned with the question "What causes inductive learning to be difficult?" and Chapter 4 focuses on the methodological issue of how to measure inductive learning. In Chapter 5, both questions are interwoven, as the methodological aspects discussed in that Chapter clearly show the complexity of inductive learning that would otherwise not be easy to pinpoint.

In the final Chapter of this thesis, the different approaches in the Chapters 2 to 5 are summarized and interpreted in terms of a general theory of inductive learning. As put forward in the above discussed "(Non-)Mythology" and "Pressing the limits" reasons, the research presented in this thesis does support the claim that there is nothing special about inductive learning. Even the large differences between learners found in some of the tasks reported in this thesis can be easily explained with down-to-earth arguments; as these differences are largely due to differences in the learners' assumptions associated with the discovery task - not necessarily with good or bad discovery behavior. Moreover, the research reported in this thesis suggest a refinement of the claim as put forward in the influential SDDS accounts (Klahr & Dunbar, 1988) that inductive/discovery learning is mainly driven by hypotheses. That is, instead of playing a central role, hypotheses seem to play a relative minor role compared to the major role of experiment construction and interpretation.