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VARIATIONS IN EXPERTISE: IMPLICATIONS FOR THE DESIGN OF ASSISTANCE SYSTEMS

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SUMMARY
The paper presents an investigation of the differences between two experts in the same domain. The observed differences concern comparisons between domain objects, rule justifications (technical vs.pragmatic justifications, naïve physics reasoning), and categorical knowledge (logic, level, and extension of the categorization). Differences are attributed to the prior experience of the two experts (workshop vs.laboratory). Implications for knowledge elicitation and for the design of assistance tools are presented.
KEYWORDS. Expertise, Knowledge acquisition, Types of knowledge, Types of expertise, Support tools, Assistance systems.

RESUME
Après une présentation critique des études sur l'expertise, cet article expose les résultats d'une étude sur les différences entre deux experts dans le même domaine (conception de procédures de fabrication de pièces). Les différences observées portent sur les comparaisons que les experts font entre des objets du domaine, leurs justifications des règles qu'ils adoptent (justifications techniques ou pragmatiques; explications de type "physique naïve") et leurs catégorisations (la logique de description des catégories, le niveau de leur description, et l'extension de leurs catégorisations). Les différences sont attribuées à l'expérience antérieure des deux experts (atelier vs. laboratoire). Des implications pour l'acquisition de connaissances et la conception d'outils d'assistance sont présentées.
MOTS-CLES. Expertise, Acquisition de connaissances, Types de connaissances, Types d'expertise, Outils d'assistance, Systèmes d'assistance

EXPERT-NOVICE DIFFERENCES AND DIFFERENCES BETWEEN EXPERTS

Expert-novice differences

Research about inter-individual differences in fulfilling a task has mostly dealt with variations in level of expertise. The observed differences between experts and novices may concern problem representation or goal representation.
Concerning problem representation, novices and experts differ first in the object being represented (Adelson, 1984). Second, novices tend to use a syntactic (or: surface structure) categorization of the problems, while experts use - or use also - a semantic (or: deep structure) categorization (Adelson, 1981; Chi et al., 1981; Novick, 1988; Weiser & Shertz, 1983). Third, experts' representations are operative, i.e. restricted to task-relevant characteristics and functionally distorted (Ochanine, 1978).
A second difference between experts and novices concerns goal representation. Bisseret (1981), analyzing the activity of air traffic controllers, concludes that novices try to maximize the accuracy of their anticipations,while experts try to minimize omission errors.

Differences between experts

Few studies have investigated the nature of the differences between experts in a domain, i.e. variations in types of expertise. What is meant here is not the fact that a given expert may be more knowledgeable in one sub-class of problems than another expert (and vice-versa), but the fact that the nature of expertise may vary.
Different prescribed tasks - on a same object -> Different representations. A number of studies have considered the effect of different tasks on the mental representation of the same objects. Coirier and Passerault (1988), and Anderson and Pichert (1978) describe the effects of interpretation bias on text representation. Similarly, Enard (1968), Boutin (1974) and Boutin and Couplan (1976) have studied the mental representation of the map possessed by different technicians in air traffic control. They show that mental maps differ from the real map, and that the mental maps differ according to the task performed. Sebillotte (1982), in a study of the diagnosis activity of obstetricians and of midwives, shows that the two groups differ in the nature of the information selected (from the patient's file) and then recalled. The information units gathered and memorized by each group correspond to the tasks usually performed by these specialists.

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All these studies can be interpreted within the framework of Ochanine's operative image theory: according to task objectives, subjects develop a restricted and distorted model of the object to process; this model is more suited to the task than a "true", "objective" representation.

The same prescribed task + different representations -> Different effective tasks. Other studies indicate that subjects having the same prescribed task may develop different perspectives on this task: the consequence is that different effective tasks are performed. Drass (1988) has conducted a study on two categories of hospital workers: nurse practitioners (NPs) and physician assistants (PAs). NPs and PAs are allotted the same task. The author shows that the two groups have different representations of their tasks, PAs emphasizing the curative activity, and NPs the prevention activity. This leads to different behaviors during medical interviews.

Delahaut (1966) has reported similar observations in a study of technicians in a process control task. The author identifies two modes of controlling the process, differing according to the goals the subjects set themselves. Some technicians attempt to optimize planning, i.e. to respect the deadlines of production. Others attempt to optimize process management, i.e. to minimize adjustments on the machine by producing larger sets of the same product.

These two studies cover situations in which subjects place additional constraints on the task to be performed. So the prescribed task may be the same, but different effective tasks are fulfilled.

All studies presented above show that, on the one hand, different tasks may lead to different representations of the object of this task, and, on the other hand, different representations of the object of a task (different "perspectives") may lead to different task fulfillment.

A COMPARISON BETWEEN TWO EXPERTS IN THE SAME DOMAIN

The domain of expertise and the task

The expertise under study concerns the "preparation of elements in compound materials", i.e. the definition of the procedures to be used for the production of a new element made up of this type of very light and strong material, in the context of the aerospace industry.

Subjects

The goal of the study was to gather the knowledge of an expert preparer (expert-1, in this text). However, for methodological reasons, and although the study was focused on the activity of expert-1, a second expert in the preparation task (expert-2) was also studied.

Expert-1 has acquired most of his experience in the workshop, expert-2 in the laboratory. At the time of the study, expert-1 managed all development projects in the preparation division, expert-2 assisted the head of the division for all questions concerning the preparation task. Both subjects were considered experts in the domain by their peers and superiors.

Because expert-1 was about to retire, and because he was requested to concentrate on this study, he was not given new problems to handle. This forbade the use of some methods, as the observation of a real design activity (see Visser & Morais, 1988). The task was also difficult to study experimentally (i.e. by proposing a problem to be solved), because design, in this specific situation, is a rather long process, extending on weeks. We had thus to rely on methods such as the study of past cases or the analysis of incidents (see Visser & Falzon, 1988).

RESULTS

The differences between the two experts concern the comparisons between objects, the justifications of the rules, and the categorical knowledge (logic, level, and extension of the categorization). During the study, expert-1 was requested to provide a categorization of the elements he had designed in the past. Expert-2 was not explicitly requested to provide a categorization, but he did gave one in the interviews.

Comparisons between objects

Expert-1 describes objects and their attributes. For instance:

To make a sandwich according to the classical procedure, one uses coatings, polymerized at a particular temperature, which one sticks with a film of glue on each face of a strip, for example, in honeycomb.

On top of such descriptions, expert-2 spontaneously provides global comparisons between objects (i.e. tools, procedures, materials). For instance:

Self-stiffened monolithic elements are efficient for bending constraints, sandwich elements are efficient for compression constraints.

A possible interpretation of this result is that expert-2's past task (the laboratory) implied comparisons between different techniques or materials, in order to provide advice on the choice of a technique or of a material. This is not the case for expert-1: he has to find a preparation procedure which respects these choices (which are imposed on him by the laboratory

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or by the research department). This difference in knowledge is thus probably caused, at least in part, by a difference in the nature of the task.

Rules justification
Pragmatical vs.technical justifications. The two experts differ in the way they justify the rules they use. The nature of the differences is most certainly caused by the difference in their past professional experience.
Expert-1 comes from the workshop, and has thus acquired a large body of pragmatical knowledge. Many justifications of the design rules he uses have a pragmatical nature, that is, they are based on a state of affairs at a moment t. For justifying, he refers, for example, to the facts that:
- the craftsmen of the workshop forget certain things; they sometimes drop pieces they work on; they prefer to work with some materials, or tools; they leave, and new craftsmen arrive; etc.
- the machines are in different buildings, so pieces may have to be moved, so they may fall or be hurt, they may be too big, or too heavy, etc.
- suppliers do not have everything in stock, so one has to order certain materials or pieces some time before they are needed to be worked on, or, if one is in a hurry -which is often the case- one may decide to use one material rather than another, because the one selected is out of stock; etc.
Expert-2 comes from the laboratory, and generally provides technical justifications, based on principles, laws of physics or chemistry. Here is an example, concerning pressure application as a function of resin rate within the material. First the practical rules, then the technical justifications.

Rules
R: If resin rate within the material = 30% (i.e. no resin to get rid of), get pressure up right at the beginning of heating
R: If resin rate within the material > 30%, do not apply pressure at the beginning of heating period
R: If resin rate within the material > 30%, the moment of pressure application is determined by the speed of temperature rise of the support. The quicker the rise, the earlier the pressure should be applied
R: The preceding rule is affected by the age of the resin

Rules justification
J: If pressure is put too early, then too much resin is expelled
J: If too much resin is expelled, then porosity caused by bad sticking of the fibers (lack of resin)
J: If pressure is put too late or if pressure drops, then bad compression
J: If bad compression, then porosity caused by bad sticking of the fibers (lack of contact between the fibers)
J: If porosity > 3%, then bad mechanical characteristics (less tolerance to efforts) and bad ageing of the material (e.g. permeability)

Concerning the justifications, another difference between the two experts is that, in some cases, the justifications provided by expert-1 may be partial. For instance, expert-1 specifies that
The resin rate required for an element depends on the mechanical qualities sought for.
but would be unable to determine these mechanical qualities, or to evaluate, according to these, the resin rate. He knows that one should not use old resins, because "getting older, resins loose characteristics", but he does not know which characteristics and why.
Again, the differences between the two experts can be explained by the difference of their respective tasks. Expert-2 provides more numerous technical justifications because his competence has a technical nature.

Naïve physics. Another striking feature of expert-1's justifications is the occurrence of naïve physics explanations. However, the status of these explanations is debatable. Three interpretations are possible:
- naïve physics explanations may belong to expert-1's beliefs in the domain: we may speak in that case of incorrect justifications;
- naïve physics explanations may be the result of naïve questioning: since the experimenter does not situate precisely the limits of the domain of competence of the expert, he may ask questions outside this domain of competence. Expert-1's cooperative behavior may then push him to the production of an incorrect knowledge unit, which otherwise would never have appeared;

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- lastly, it may well be the case that the expert estimates that a precise, exact answer is not desirable to provide if he wants to be understood. The expert may create a simplified answer for the sake of the experimenter. Naïve physics may be an adapted answer for naïve experimenters!

Categorical knowledge
Logic of description. According to expert-1, the categorization of the pieces results of the interaction of two factors: the shape of the elements and the materials they are made of. However, this rule is not completely respected. In particular, some pieces are set apart because their production is highly constrained (in terms of dimensional precision), which leads to the use of specific methods, or because they have constituted major development efforts.
A very striking difference between the categorizations of the two experts is that materials or methods are not taken into account in expert-2's categorization. His categorization is abstract, in the sense that it is independent of the task.
Level of description. A second difference lies in the level of description of the categories. For expert-2, description is made at a level independent of the cases. Categories are given general names (such as "revolution structures"), and cases appear as instances of categories. In contrast, expert-1 shows a tendency to present cases of products (e.g. a particular type of antenna), and not only abstract categories. In other words, expert-2 provides an abstract categorization, situating the cases he presents in categories identified by general terms, while expert-1 uses a more case-dependent categorization.
Extension of the categorization. A final difference concerns the extension of the categorization. The cases presented by expert-1 can be mapped onto the categorization provided by expert-2. The result of this mapping indicates that several classes of expert-2's categorization have not been exemplified by expert-1 (of course, the fact that expert-1 provides an example of a specific category says nothing about his knowledge of the category itself: he may, or may not, know its existence as a category). However, it is to be noted that expert-2's more extensive categorization includes classes that have not been used for a long time - if they have ever been used outside the laboratory.
Again, this can be interpreted as indicating the use by expert-1 of an operative categorization, which keeps the categories useful for his task and not categories that, possibly, have never been instantiated.

DISCUSSION

Operative knowledge vs. general knowledge
Some of the reported results are puzzling. Although expert-1 was considered as the domain expert, the information provided by expert-2 is "richer", and seems to contain less "errors" (such as "naïve physics" knowledge units). Several reasons may be considered to explain these results.
A first hypothesis is that more information is obtained only because a second expert is available, and not because of the characteristics of expert-2: a second expert, whoever he is, allows to gather more data. However, this does not explain the differences in the nature of the data.
Another hypothesis is that expert-2 is more competent in the domain than expert-1. This hypothesis has to be rejected since expert-1 is acknowledged as the expert in the domain.
Lastly, a third hypothesis is that the two experts differ in the same way as a teacher differs from a practitioner, in the same way as an epistemic subject differs from an operative subject. The knowledge of expert-1 is molded by his experience in the domain, embedded in practice. A good instance of this fact lies in the categorization he provides, which depends on the task to be performed. Expert-2's competence has also been acquired through experience, but his task - the task of the laboratory - was, by definition, to build case-independent knowledge units. Thus, his task implied the elaboration and formalization of abstract concepts.

Implications for the design of knowledge-based systems
One important difference between the two experts lies in the amount and type of justificative knowledge they exhibit. The justifications provided by expert-2 are more numerous, more often exact and differently grounded than the justifications given by expert-1. This is of course caused by past experience. Expert-2's experience in the laboratory has led him to know the technical rules underlying practical rules.
The differences between the two experts are thus easily explained. The question is now: to what extent justifications, and what kind of justifications, are needed in order to design an assistance system ?
A first answer is provided by the work of Clancey (1983), which has demonstrated that expert rules are not enough to provide tutoring assistance. Eliciting justifications is thus necessary for pedagogical reasons.
A second reason for eliciting justifications is that some of the rules used by expert-1 are not deeply rooted in the world of physics. Many of his justifications are either normative or pragmatical, i.e. based on a state of affairs, on experience or on technical know-how (see Visser & Falzon, 1988). These bases may change, which affects the validity of these knowledge

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units. Knowing the underlying technical justifications (which are less subject to change) is useful both for updating the knowledge base and for using the knowledge base in tutoring situations.
As we have seen, one can be an expert and still not have a deep knowledge of the justifications. Thus, and especially when the elicitation is done in the objective of designing an intelligent tutoring system (or an expert system with justification capabilities), it is necessary to have access to a subject whose past experience has allowed to acquire these justifications. He may not always be the expert in charge of the activity.

Implications for design aids
A second result of this study concerns the categorization activity. Expert-1 does not provide an abstract categorization of the problems. There are two (non-exclusive) ways to interpret this result:
- one is that his task does not require a categorization activity: in that case, expert-1's not presenting an abstract categorization is not surprising;
- a second interpretation is that the practice of the task does not give rise to the elaboration of an abstract categorization.
The first interpretation is highly unlikely. All design activities are characterized by the use of past solutions (see Visser, 1987, 1988), which means retrieving a problem (more or less) similar to the one being tackled. This pattern-matching activity may not make use of an abstract categorization; still, it consists in classifying the new problem as a "kind of" past problem.
The second interpretation seems more satisfying, since it is corroborated by many experimental results. The task of abstracting a schema from exemplars (which is fundamental in the development of an abstract categorization) is a very difficult one when the number of exemplars met and/or processed is small (Gick & Holyoak, 1983). This result is in keeping with what we know about schema elaboration: schemas of prototypical situations are built and tuned under the influence of repetition (Anderson, 1982; Ochanine, 1978; Rasmussen, 1983). In the situation considered, as in many design activities, problem repetition is rare. Thus, expert-1's inability to present a categorization of the problems may be due to the scarcity of the source problems.
What could be done in order to help the expert in his task ? A possible solution would be the design of an interactive categorization aid, which could assist the user in elaborating abstract categories and in retrieving analogous problems.
<u>Assisting category abstraction</u>. The task of this system would begin after the declaration by the expert of a similarity between two problems. The system would then elaborate a common abstract representation of the two problems, using for this task the attributes that have been described by the system user. It would then situate this representation in the tree of abstract representations (previously built). Both the representation and its position would have to be acknowledged by the expert before being integrated. This verification by the user is necessary for two reasons.
First, some of the descriptive attributes mentioned by the user may be irrelevant for categorization. For instance, the two descriptions may give a similar value for an attribute (e.g the value "yellow" for the attribute "colour"), but the value and/or the attribute may be totally irrelevant in the context of the task.
Second, when localizing a new case, the system may wish to modify the existing hierarchy, for example, by creating new categories. These modifications may not be wished by the subject, even though they might be possible. For instance, suppose the system has to categorize a new bird "ostrich", and notices it cannot fly. Supposing also that the system already possesses a "bird" category, stating that birds fly, it may wish to create two new categories "birds that fly" and "birds that do not fly", and to specify "ostrich" as an instance of the last category. However, another organization is possible: the user may wish to stick to the first categorization, and simply add "ostrich" as a special case of bird (an exception) that does not fly. There is not one "good" solution: the choice is task-dependent. This is why we think that the subject is the best judge of the solution to be adopted.
<u>Assisting problem retrieval</u>. Such a system would not accomplish the task of source problem retrieval, since this is done quite well by the expert, and since this task is probably rather difficult for a system (on which aspects should two problems be compared ?). However, it could help this process. Experimental results have shown that analogy is more difficult when large differences between the surface features of the (source and target) problems exist (Holyoak & Koh, 1987; Ross, 1987). Thus, in such cases, the expert may not be able to retrieve a source analogue. The system could then help:
- first by attempting to match the problem with the already built categories; this process can be facilitated by guiding users in their description of the problem (by proposing category attributes);
- second by selecting the best matches;
- third, by proposing exemplars. If the user is satisfied with the exemplars, the categorization is implicitly validated.

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