REPRESENTATION AND ACQUISITION OF KNOWLEDGE OF FUNCTIONAL SYSTEMS

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ABSTRACT

Many experimental studies have shown that learning and memorization of complex information are strongly influenced by the learners' prior knowledge. Thus, detailed analyses of the structures and the processes involved in learning and memorization require precise assessment of the learner's prior knowledge in relation to the characteristics of the domain to be acquired.
We have developed a formalization in terms of systems: relational, transformational, teleological (functional and intentional) which permits us to simultaneously describe that domain being acquired, the representaion of the acquiring organism, and our representation of that representation.
Here, we will report a study in which this formalization was employed in assessing the representation that students with different levels of knowledge about automobile mechanics have of a functional system: the starter system of an automobile.
The predictions made by this formalization were compared with the performances of three groups of students with different levels of knowledge on a series of four tasks: free interview, causal questioning, completing lacunary event triples, and a multiple choice questionaire on the existence of events and causal relations. The criterium used to choose these four tasks was that they differ according to the demands they make in the retrieval of stored information in memory.
The results show that:
(i) subjects with a good level of knowledge have a representation organized in a fuctional autonomous system organized in sub-systems, while
(ii) subjects with lower levels of knowledge do not have a representation organized as a functional system, and
(iii) subjects from the intermediate group built a representation organized as a functional autonomous system but containing less information and more poorly organized in sub-systems.

The emergence of cognitive research on the acquisition of knowledge from texts has led to a break from an approach centered exclusively on text and linguistic knowledge and to take into account the specific characteristics of those type-representations that are knowledge and beliefs (Denhière & Baudet, 1988). While processing a text, an individual constructs several types of representation from the textual information. In the description of those representations, an important step has been the introduction of the concept of mental model (Johnson-Laird, 1983) or situation model (van Dijk & Kintsch, 1983) to conceptualize the world representation that individuals build through their experiences and their learning, and which they activate during the reading of a text. The concept of a model, however, only has value if the model is rigorously defined and if the descriptions of the world and other representations that an individual has of it are clearly specified. So, we propose an analysis in terms of systems as an attempt to produce a conceptualization that allows for a precise description of the representation that we have of the world and of the representation of the representation that the learner builds for himself (Baudet & Denhière, in press).

RECOURSE TO THE NOTION OF SYSTEM

To characterize our description of a complex domain involving several individuals or objects, their characteristics and their relations, and our representation of the learner's representation, we have developed a model depicting relational, transformational or teleological systems, functional or intentional (see Baudet and Denhière, 1988).

A **relational system** represents complex stative situations : states in which are found individuals or objects for a possible world. Defined by intension, a relational system is a collection of individuals affected by the definition of one or several relations between these individuals. Formally, a relational system is a sequence <I, R1, ..., Rn> where I is a non-null set and R1, ..., Rn are relations that apply to elements of I (see Coombs, Dawes and Tversky, 1975).

A **transformational system** represents complex events: transformation sequences of stative situations. Defined by intension, a transformational system is used to transform; i. e. in an interval of time t : i, j, it is characterized by modifications in the " normal course of the world", changes in the "natural tendency" of successive states of the system either to remain as is (conservation of states) or to change (events) (von Wright, 1967; François, 1988).

A **teleological system** represents structures and behaviors of organisms : sets of interrelated functional units. When the functional units ---human beings and by extension, animals--- are credited with intentionality, they will be considered to be intentional systems; when they are components of a technical or biological device they will be referred to as functional systems. Defined by intension, these systems are teleological, i. e. they form a functional unit. In an interval of time t : i, j, the initial state of the system, defined by the individuals initially present, their relationships and the initial values of their attributes is modified so as to attain a configuration (final state) which constitutes the target goal of the system. Each modification intervening during interval of time t : i, j, functions as a means of achieving this goal,that is, it creates the necessary conditions in the circumstances (see Mackie, 1974) to reach this goal.

CAUSAL CONNECTIONS

Causal connections are crucial to transformational and teleological systems. The present model draws on the philosophy of action (von Wright, 1967; Mackie, 1974; Trabasso & van den Broek, 1985) by taking account of knowledge about the construction of state, event, and action representations, and naïve causality. Recent experimental work (Hilton and Slugoski, 1986) is in line with the hypothesis that the cognitive representation of causal relations is built up via a causal explanatory operation (search through a set of events for the cause of a given event or state) which implements contrafactual reasoning based on the criterium of necessary condition and judgment of naturalness of events in the situation. Thus, the naïve concept of causality which will be activated by the occurrence of a causal connection in language or in the world can be interpreted as (Mackie, 1974) : **X Causes Y : the occurrence of X is a necessary condition, in the circumstances, for the occurrence of Y.** Causal connections are built in relation to a specific context : the circumstances. The cause and the effect represent modifications in the normal course of the world: "Cause is an INUS condition (Insufficient but Necessary part of an Unnecessary but Sufficient condition), a modification introduced into the causal field which, in the absence of any other modification, is a necessary condition for the effect to occur" (Mackie, 1974). By causal field we mean the set of necessary conditions for the occurence of the effet which are not modification in the normal course of the world.

THE TELEOLOGICAL DESCRIPTION OF A FUNCTIONAL SYSTEM

In general, a teleological description of a system can be expressed as follows (see Mackie, 1974) : **I has C in E because C in E leads to B**, in which **I** = individual or set of individuals, **C** = behavior of a system described by the sequence of states or events, **E** = environment or circumstances, and **B** = goal of system (final state aimed at by the system). At the same level of analysis, in the case of a complex description, the system must be decomposed into subsystems whose description is more elementary. The teleological nature of the functional system, i.e. its hierarchically structured organization into goals/subgoals makes this decomposition possible. This decomposition reflects the structure of reality : the functional system is tangible evidence of problem solving activity implemented by the designer. Each subsystem, like the system itself, makes up a functional unit. It is characterized by its role in the general functioning of the system : the final state of the subsystem serves as a subgoal of the system. The system is thus analyzed as a set of hierarchically organized functional units, a tree structure. These units are related causally, temporally and topologically. This yields the following descriptions for a functional system:

(i) Causal path description of system functioning :

The description consists of establishing a sequence of actions, events and states which express a temporal sequence of system functioning. A state is described by a relational system and an event and an actions are described by a modification of a relational system. Local semantic coherence arises from the explanation of relations between actions, events, and states.

(ii) Teleological description of system functioning :

This is represented by a tree structure whose original node is the goal of the system. The subordinate nodes represent subgoals of the system, which must be attained for the main goal to be accomplished. These subordinate nodes are the macro-events of the system. The occurrence of these macro-events is itself conditioned by the occurrence of events represented by the nodes immediately below them. The construction of a structure of this type thus consists of a categorization and a hierarchization of events into goals as a function of the goals assigned to the system, which may or may not violate the temporal sequence. The global semantic coherence is ensured by this goal structure.

EXPERIMENTS TO TEST THE VALIDITY OF THE MODEL

We carried out four tasks (free interview, causal questioning, completing lacunary event triples, and multiple choice questionaires on the existence of events and causal relations) with three groups of students (n=7) having different levels of knowledge of car mechanics (G1>G2>G3). Our objective was to identify their representation of the starter system.
We put forward the two following general hypothesis :

H1 : The acquisition of knowledge about a functional system is an activity which results in the construction of a coherent signification which corresponds to the description of a functional system as proposed above.

H2 : Subjects in group G1 with a good knowledge of the starter system will have a representation of this system which corresponds to our description of a functional system. Subjects from group G3 will not have constructed a representation of the starter system as an autonomous functional system. The group G2, who have demonstrated a lower level of acquisition than group G1 should either lack a representation of the starter system organized as an autonomous functional system, even though they know more elements of this system than G3, or have a representation of the starter system organized as an autonomous functional system but, in relation to group G1, this should be less elaborated insofar as it should contain fewer elements and be less well organized with respect to sub-systems.

The following predictions are deduced from the hypothesis 1 :

Distance Effect (D). The majority of recalled and recognized information (objects, events, relations) in the interview protocols and the questionnaires will belong to the starter system. In the protocols, the number of intrusions belonging to systems other than the starter system will be inversely proportional to the distance of that system from the starter system : START SYST > ADJ SYST > OTHER SYST.

Position effect (P) in the sub-systems. The initial and final event of a sub-system will have a higher probability of being expressed in the interview protocols and questionnaires than the intermediate events (boundary effect). Furthermore, the teleological nature of the representation allows us to predict a higher probability of occurrence for the final event leading to the realization of the sub-system's goal: FINAL > INITIAL >INTERMEDIATE.

*Interaction T * S* between the type of task (T) (interview vs. questionnaire) and the level of structure of the information (S) (micro- vs. macro-proposition): providing assistance to access information (questionnaire) allows for easier recovery for that information which our analysis in terms of systems identifies as belonging to the micro-structure rather than the macro-structure.

From the second general hypothesis H2 we can predict the following interactions:

*Interaction D * K* between the factors distance (D) and knowledge level (K) predicted on the basis of the hypothesis (H2): the distance effect will not be observed for group G3 whose cognitive representation is not organized as a functional system.

*Interaction M * K* between the membership level (M) and the knowledge level (K): the effect of membership level in the system will not be observed for group G3.

*Interaction T * S * K* between the type of task (T), the level of structure (S) and the knowledge level (K): the interaction in prediction 5 will not be observed for group G3 whose cognitive representation is not organized as a functional system.

Tasks

The three groups participated in four tasks organized as follows:
- phase 1: free interview followed by causal questioning,
- phase 2: incomplete event triples; this immediately succeeds phase 1,
- phase 3: multiple choice questionnaire on the existence of events and causal relations; this follows phase 2 after a one week delay.

Tasks executed by the subjects are assumed to vary in terms of the activities involved in the recovery of knowledge from memory (Baudet, 1988).

Protocol analysis :

For each subject we thus have an interview protocol and a questioning protocol.

First, an inventory of all objects, states, events and actions mentioned in the protocols is made and they are categorized as a function of their system membership: starter system, systems adjacent to the starter system, other systems (Blaizet, Cheritel, Legros, 1988). States, events and actions are then categorized in terms of their membership level within a sub-system: initial, intermediate and final positions. Then they are categorized in micro- and macro-propositions depending on whether they represent micro- or macro-events. Finally, we make an inventory of the relations made by subjects among the states, events and actions. They are first classified with respect to their position in the structure analyzed in terms of systems: starter intra-system, inter-systems, and other intra-systems. The relations are then categorized in terms of their nature : CAUSE (C), ENABLING (E), GOAL (G), TEMPORAL (T), SPECIFICATION (SP).

Results :

We present only the results of the first three tasks. The results of the multiple choice questionnaires on the existence of events and causal relations confirm the results obtained with the previous ones.

1. Free interview and causal questioning :

1. 1. Objects :

1: Distance effect (D) : The average number of objects mentioned in the interview protocols and questionnaires were ordered according to the predicted hierarchy : $F_{2,36} = 55.6$; $p<.001$. SYST (m=16.2) > ADJSYST (m=6.1) > OTHER SYST (m=1.0).

2: Interaction K * D . There is a significant difference between the mean number of objects belonging to the starter system and those objects belonging to adjacents systems for groups G1 and G2, but not for G3 : $F_{4,36} = 9.33$; $p<.01$.

1. 2. Events :

1: Distance effect (D): The mean number of events in the interview protocols and questionnaires was ordered according to the predicted hierarchy : $F_{2,36} = 33.6$; $p<.01$. SYST (m=4.9) > ADJSYST (m=2.0) > OTHER SYST (m= 0.4).

2: Interaction K * D. There is a significant difference between the mean number of events belonging to the starter system and those events belonging to adjacents systems for groups G1 and G2, but not for G3 : $F_{4,36} = 7.8$; $p<.01$.

3: Position effect for the events in the sub-system (P): The average number of events in the interview protocols and questionnaires was ordered according to the predicted hierarchy : $F_{2,36} = 115.0$; $p<.001$. FINAL (m=13.2) > INITIAL (m=6.4) >INTERMEDIATE (m=2.4).

4: Interaction K * P. An analysis of the simple effects shows that only in the final position do significant differences occur between G1 and the other two groups : $F_{4,36} = 7.8$; $p<.01$.

5: Interaction T * S. The questioning which facilitates the recovery of information, affects the micro-structure mainly : $F_{1,18} = 6.11$; $p=.02$.

6: Interaction K * T * S approaches significance: $F_{2,18} = 2.7$; $p=.09$. The questioning resulted in a relative improvement of the recovery of information pertaining to the micro-structure for groups G1 and G2 but not for G3 (multiple comparisons of the means were all significant $p=.05$).

1. 3. Relations :

1: Membership level in the system (M). The average number of relations mentioned in the interview protocols and questionnaires is ordered according to the predicted hierarchy : $F_{2,36} = 10.6$; $p<.01$. INTRASYST (m=10.6) > INTERSYST (m=3.8) > INTRASYST≠ (m=3.0).

2: Interaction K * M. For groups G1 and G2 the number of relations internal to the starter system was significantly greater than the relations belonging to either of the other two system categories and this was not the case for group G3: $F_{4,36} = 4.124$; $p<.001$.

3: Interaction M * T. The questioning procedure was effective mainly in recovering relations internal to the starter system : $F_{2,36} = 13.50$ $p<.001$.

4: Interaction M * T * K. The preceding interaction was not observed for group G3 : $F_{4,36} = 3.70$; $p=.01$.

5: Interaction M * R. Subjects use more CAUSE relations than GOAL relations within the system and this is not the case between systems : $F_{10,180} = 4.94$; $p <.001$.

6: Interaction M* R * K. The three groups of subjects use more CAUSE relations than GOAL relations within the starter system. However, with respect to the relations between systems one sees the contrary: subjects from groups G1 and G2 establish more GOAL relations than CAUSE relations while subjects in group G3 use more CAUSE relations than GOAL: $F_{20,180} = 2.54$; $p <.01$.

2. Incomplete event triples :

1: Distance effect (D) to the sub-system: . The frequency of response types follow the predicted hierarchy ($F_{3,54} = 11.9$; $p<.01$) :

S-SUBSYST	>	S-SYST	>	OTHER SYST	(OMISSIONS)
.363	>	.179	>	.095	(.363)

2: Interaction between D * K: $F_{6,54} = 12.0$: $p<.01$. Table 4 below shows the different patterns of response frequencies according to the groups:

G1: S-SUBSYST > S-SYST > OTHER SYST : .625 > .250 > .017
G2: S-SUBSYST = S-SYST > OTHER SYST : .375 > .232 > .054
G3: no significant difference : .090 > .050 > .021

3: Boundary effect of sub-systems (B): The significant interaction C * P: $F_{3,54} = 5.9$; $p<.01$ shows that the correct responses are more numerous when the gap occurs at the border of two sub-systems rather than within a system.

CONCLUSIONS

The four experiments provide a body of results compatible with the hypothesis that acquiring knowledge about a functional system is an activity which culminates in the construction of a coherent network which corresponds to the description of the proposed functional system. They also provide information as to what might be the appropriate steps necessary for achieving mastery of a complex technical system: from the incoherent representation of some events, states or actions to a cohesive organization. That cohesive unit is a functional system capable of differentiating this organization into sub-units of the same type (sub-systems units at a high level of the functional system). Actually when we compare the performances of the three groups of subjects having different knowledge levels, it seems that the group which was most knowledgeable constructed a representation organized in functional systems and sub-systems. On the other hand the group which received the same instruction as the previous one but which showed a less well developed knowledge about the system demonstrated by their performance that they built a representation organized as a functional system but not with sub-systems. Their cognitive representations of the starter systems differs from those of the preceding group both in terms of fewer real units represented and also by the structure of these units into a system which could be decomposed into functional sub-systems with difficulty, if at all. Finally, the group which received no instruction directly concerning the starter system but which has general knowledge and intuition about car mechanics following an introductory course, performs in such a way as to indicate that they do not differentiate the starter system from those other systems which make up a technical object like a car. In particular they make no distinction between the starter system and adjacent systems such as the thermal internal combustion engine, the ignition system, the energy supplying system.

Our analysis in terms of systems produces a conceptualization that allows for a precise description of the representation that we have of the world and of the representation of the representation that the learner builds for himself. It allows us to formulate in new terms, questions regarding comprehension and text production. It is a necessary condition for the detailed study of the processing of complex verbal information such as the interplay of the linguistic and logico-linguistic elements of the text, the cognitive characteristics of individuals and the characteristics of the world represented in a text. Our model allows us to seriously consider the construction of computerized systems to assist learning in complex domains (see Tapiero, Poitrenaud, Denhière, 1988).

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