Evaluation of ITS Design: The Case of Shiva-géographe

Nicolas Balacheff, Lamiel Figue-Henric

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N. Balacheff*, L. Figue-Henric**

1. INTRODUCTION.

The target of the SHIVA-géographe project is to study the relationships between the epistemological constrainsts of a knowledge domain, here a systems approach of geography, and the specific constraints of the effective implementation of a teaching process using means provided by Artificial Intelligence. This field of questioning is currently emerging because of recent advances of *didactique* as a scientific discipline (Brousseau 1986) together with the development of knowledge in Intelligent Tutoring Systems design.

In this context, the AGDI[1] SHIVA developed in the frame of the DELTA AAT[2] Project from the European Community (Baker and Bessière 1990), is a prototypic example of an environment for ITS design and implementation, insofar as it keeps the current dominant principle of a separation between modelling the content to be taught and modelling didactical interaction. The didactical engine of SHIVA is ECAL[3], an ITS shell developped by Elsom-Cook (1989). The knowledge domain at the core of the project is related to a planning problem, which is the study of how a ground water table, used for supplying a large urban area, works. This problem is considered in the frame of a systems approach in geography, its complexity makes significant the study we undertake. As a matter of fact, we are in a field of knowledge which is neither strictly procedural, nor strictly encyclopedic as it has been very often the case of geographical tutorial systems (for example: Carbonnell 1970; Duchastel 1989).

This paper mainly focuses on the relationships between a conceptual analysis from the point of view of geographers and the conceptual organisation resulting from the ECAL processing of the implemented specifications of the SHIVA-géographe authors.

2. Principles of a didactical analysis

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* DidaTech, Laboratoire LSD2-IMAG, CNRS et Université Joseph Fourier, BP 53, 38041 Grenoble Cedex 9, France
** Institut de Géographie Alpine, Université Joseph Fourier, BP 53, 38041 Grenoble Cedex 9, France

[1] AGDI : Atelier de Génie Didacticiel Intelligent

[2] DELTA (Developing European Learning through Technological Advance) is a coordinated programme of R & D from the European Community, AAT (Advanced Authoring Tools) is a project part of this programme runned by M. Elsom-Cook (Open University).

[3] ECAL: Enhanced Computer Assisted Learning

The fundamental principle of a didactical analysis is to consider the learning process from the point of view of the knowledge built by the student in the context of the constraints specific to teaching situations and with reference to a given content to be taught (Brousseau, 1986). In the present context, this knowledge is built up through the interaction beween the student and the ITS. The many different ways of representing knowledge in a computer environment increase the complexity of the situation:

• Several choices must be made concerning the internal structure and the external interface. Many models are possible. However these choices are likely to modify the knowledge itself through a process of *computational transposition* (Balacheff 1993). The computational transposition is a process to adapt the knowledge for its implementation and use in a computer-based learning environment. The choice of a quantitative modelling (simulation) or a qualitative modelling (a rule-based system or a semantic network) doesn't allow to give account, in the same way, of a given knowledge, and hence it doesn't allow a similar reconstruction of the meaning by the student in one or the other case. An open question remains, that of the determination of the domain of epistemological validity of the way of modelling which has been choosen with respect to the target knowledge (Balacheff et Sutherland 1994). In this case study, the knowledge modelling is carried out at two distinct levels: at the level of the teaching units which is completely controlled by the authors of the ITS, and at the level of the semantic network, which in this case was being built by ECAL. It is also possible to distinguish in the design of the teaching units on the one hand the organization of knowledge from the point of view of its logical structure, and on the other hand the representation of knowledge as a series of "screen pages" successively presented during a session.

• The "modelling" of the student and the explicit or implicit modelling of the *didactical* interaction between the student and the ITS, are components of the same problem. These questions go far beyond the questioning of the classical choices, such as "tutoring", "coaching", "guided discovery learning" as style of interaction, or "overlay", "mal-rule" or "buggy" as type of student modelling. It is necessary to examine in a detailed way the specifications of the algorithms choosen for the elaborations of the feedback loops, specially the choice of their moment (immediat or not) and of the media used (text, images, simulations ...). In the case of SHIVA, the knowledge of the student is considered at three different levels: at the level of units used for evaluation, at the level of units of presentation, and finally at the level of ECAL, as a partially weighted evaluation model.

• In the relationship between students and computer the interface clearly plays a crucial role. It is through the interface that students acquire and learn a specific symbolic mode of communication which can modify their learning process, even if this communication occurs in a graphic mode or by direct "manipulation". The question can be raised also about the role of students experience in the use of computers in the construction of his knowledge; we did not consider this aspect in this study.

3. DIDACTICAL ANALYSIS AND SPECIFICATIONS IN SHIVA.

3.1. THE KNOWLEDGE DOMAIN AND THE CONTENT TO BE TAUGHT.

The knowledge domain in the case of SHIVA-géographe concerns a planning and environmental problem: the supply of water to the urban area of Nice from the alluvial ground water table in the lower valley of the river Var. The aim is to study the functioning of the alluvial ground water table, which is being to be disturbed by the growth in the population of the Côte d'Azur as a whole. This functional system has to be formulated in such a way that it may be understood by students (Le Berre 1986).

The project can be placed within a global geographical context which takes into account a number of interrelated human, social, and natural parameters. These parameters include the natural inflows and outflows of water in the alluvial ground water table, various parameters concerning the spread of the urban area with the consequent drying-out of the alluvium, and certain parameters related to the engineering works in the river bed which attempt to remedy this. The aim of SHIVA-géographe is to understand of how interactions between these parameters operate through time. In order to achieve this aim a systems approach was used for at least two reasons. First, the only way to deal with complex phenomena is to consider them as a dynamic whole. Second, when combined with information obtained from simulations, this approach allows SHIVA to be used interactively for a better understanding of the subject-matter under study. But the aim of the SHIVA project is not to introduce a student to a systems approach, and even less to the elaboration of simulation models ; these models will be used, in a "transparent" way, as a very useful pedagogical tool for thinking and knowledge acquisition.

3.2. THE DETERMINATION OF THE TEACHING UNITS AND THE CONCEPTUAL ANALYSIS.

3.2.1. The identification of the teaching units.

The problem of identifying the teaching units is somewhat tricky. Indeed there were two possible routes that could be taken. One route would be to retain only one teaching unit (the software itself), the other route would be to equate a teaching unit with a screen page. It must be pointed out that, in the context of SHIVA, one teaching unit is a classical CAL so that everything which is in this unit is *effectively* controlled by the author. The choice may be difficult as it determines who will control and take responsability for the learning process: the author or the machine.

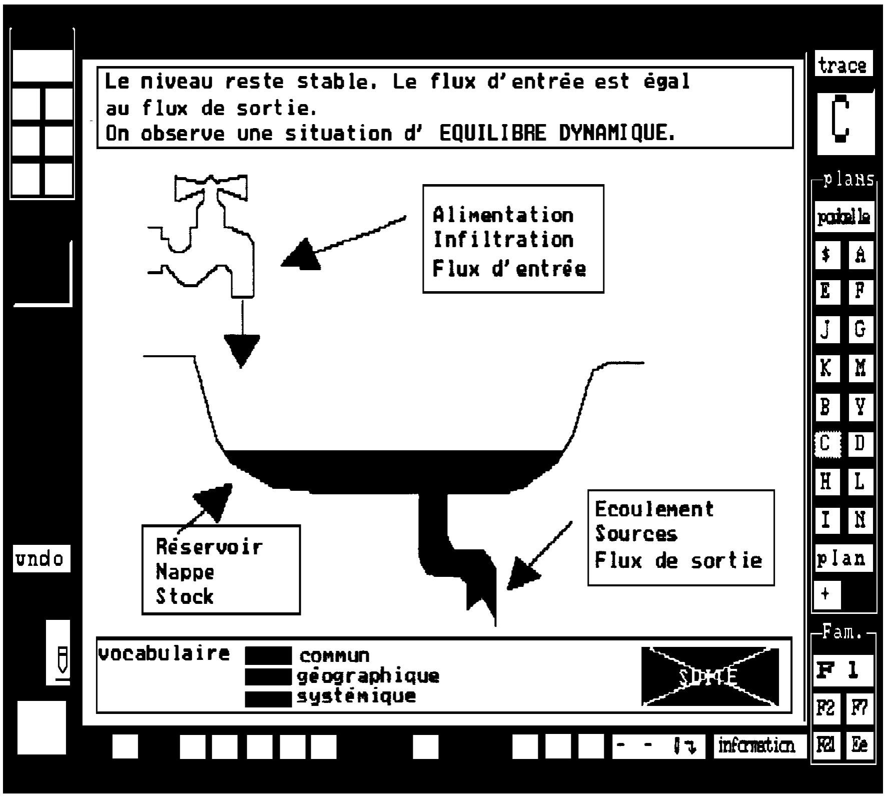
Another difficulty is due to the nature of geography itself or, more precisely, to the type of descriptive geography which is still taught in schools and often in the first year of advanced studies in France. It would be fairly natural to equate the notion of teaching unit with the notion of a task which has to be performed and/or a problem which has to be solved. The difference between these notions still is relatively unfamiliar to the teaching of geography.

According to Henri Chamussy: "*La géographie en est largement restée au stade d'une démarches descriptive et classificatoire. Elle n'a presque jamais recours explicitement à une (ou des) théorie explicative. Tout ceci aboutit au fait que l'enseignant soumet rarement des problèmes à l'étudiant; il lui enseigne des objets et des noms qui désignent ces objets. Il fait appel surtout à la mémoire et éventuellement à sa capacité à trouver un lien entre deux ou trois notions*". Students not often meet problem-solving cases in geography. In order to do so, it is necessary to rely on some thoretical framework which would enable a process of conceptualisation allowing to go beyond a common sense understanding. It is precisely the role played by the systems approach in some of the current developments of geography.

Finally, the choosen strategy consists in identifying, in an empirical way, small teaching units which are relevant from a didactical point of view (a teaching unit is related to a precise intended learning outcome). It is at the level of such units that the generation of relevant learning situations, the diagnosis of the current state of student's knowledge and the decision about necessary interactions are implemented. Relationships with other units are localy expressed by semantic descriptors, but their updating and their effective management are left to ECAL which generates the global cursus.

3.2.1.1. The overall structure of the tutorial SHIVA-géographe.

The starting point was the content analysis of the textbook by Maryse Guigo and Maryvonne Le Berre (Le Berre and Guigo 1989) for postgraduates in geography. In this textbook two types of notions are to be found: on the one hand there are geographical notions related to planning problems, and, on the other hand, there are notions of systems analysis which originate from studies into the dynamics of systems (for example Forrester 1982). The main ideas contained in this textbook have been used as a guide to the preparation of the SHIVA-géographe teaching units. To some extent, the textbook also provided a relevant method to approach the basic design and structure of the software.



The first screen image of SHIVA-géographe.

Figure 1.

One plausible initial teaching unit can be based on a model which can be described as the "metaphor of the bathtub" (fig.1). It is a conventional model for introducing the systems analysis of ground water-tables. This model presents the concepts of water storage and flow clearly and makes it easier to deal with crucial concepts such as dynamic equilibrium, reservoir capacity (the bathtub), the supply of water (the tap) and the outflow of water (the plughole).

Furthermore, this approach, which is focused on a case-study in the lower valley of the river Var, permits also a descriptive geographical approach to the study. The use of the descriptive approach allows the student to generate spontaneous ideas about the alluvial ground water table and how it works. The student can be aided in this task by using an accompanying multi-media software which includes topographical maps of the lower valley of the river Var, various geological sections, photographs, rain-fall graphs, hydrological regime graphs, etc. Thus it is possible for the student to transfer from the world of descriptive geography into the CAL model various concepts suggested by the bathtub model:

• Ground water table (in the metaphor: bathtub), alluvial material containing water; localization in the lower valley; variation in head (and not water volume); drainage basin.

• Supply of water (in the metaphor: the tap); precipitations regime, drainage basin, inflitration by precipitations. The drainage basin may be analyzed in terms of its constitutive elements (catchment area, exutoire, slopes, land cover, hydrographical network, etc.) and in terms of its functioning (water circulation by flowing down, inflitration by flow in the hydrographical network.)

• Emptying (in the metaphor: the plughole); springs and flow to the sea, rate of flow of the springs according to the head of the ground water table.

Finally, the concepts which allow the presentation of a systems model, explaining the dynamic equilibrium of the ground water table and of its functioning must be introduced: concept of stock (the ground water table itself), of input (supply), of output (emptying), feedback, interaction. Time and duration are part of this model.

3.2.1.2. The teaching units considered

The teaching units finally considered in this case study are organized in five subsets. This organization does not prejudge the structure of the knowledge in the tutoring system. It corresponds to an organization likely to allow a consistent learning process. These subsets correspond to the following topics:

VAR0: the ground water table
VAR1: the water supply
VAR2: the emptying
VAR3: the engineering works
VAR4: the systems theory.

Presently the set includes 35 teaching units. In the context of this paper, we focus on the case of VAR0 which gathers 7 teaching units.

3.2.2. The first attempts: a "naïve" approach.

The method used was that of content analysis (Posner and Rudnisky 1985) which consisted of a survey of the keywords taken from a textbook which presents the basic content to be taught, and to use those keywords as descriptors in the teaching units. The attempt to structure the information through the use of a semantic network has demonstrated an important aspect of heterogeneity which generates various inconsistencies. Indeed, within the textbook it is possible to find a vocabulary which is used at different levels of discourse. This heterogeneity arises from a number of sources:

• The need to transfer knowledge from the common sense level (which is supposed to be the students level) to a more advanced level of geographical knowledge;

• The need to integrate the verbo-conceptual level with the systems level;

• And also the level of the hierarchical organization of geographical knowledge.

For instance, the terms "rain", "precipitation" and "inflow" are three possible descriptors for only one conceptual entity, the water input. The differences between these terms correspond to the fact that they refer to different theories and practices (that is common sense, geography and systems theory respectively). Terms such as "precipitation" or "pluviometry" may be chosen as descriptors, but they relate to each other as language and metalanguage. However, this heterogeneity does not conflict with the nature of ECAL itself, as it uses only the relationships " … are descriptors of the same unit …" when building its conceptual network. Unfortunately this case study showed that this behaviour of ECAL generates difficulties in the specification of the content to be taught itself, since some intrinsic geographical structures are lost.

To solve this problem, rules had to be introduced for the description of the teaching units. We expected from these rules at least a partial restoration of the correct geographical structures. These rules can be set out as following "if...then" statements:

• ß1: If a particular concept is examined in a teaching unit, then the term for this concept has to be used as a descriptor.

• ß2: If a set of descriptors corresponds to concepts of the same class, then it is substituted by the name of this concept-class and by the name of the concepts which are the main targets of the teaching unit

Figure 2 shows the association of the teaching units and of the descriptors according to the rules ß1 et ß2 in the case of VAR0. Figure 3 shows a graphic representation of that association such as the authors can see it on the interface of SHIVA-géographe.

teaching units of VAR0	**01**	**02**	**03**	**04**	**05**	**06**	**07**
descriptors :							
Vocabulaire systémique	X	X	X				
Fonctionnement de la nappe	X	X	X		X		X
Vocabulaire géographique		X	X	X	X	X	
Typologie des nappes					X		
Réservoir	X	X	X	X	X	X	X
Model	X	X	X				
Equilibre dynamique		X	X				
Topographie			X				
Aménagement			X	X	X	X	X
Evolution			X			X	

Naïve approach: characterization of the teaching units by descriptors.

Figure 2.

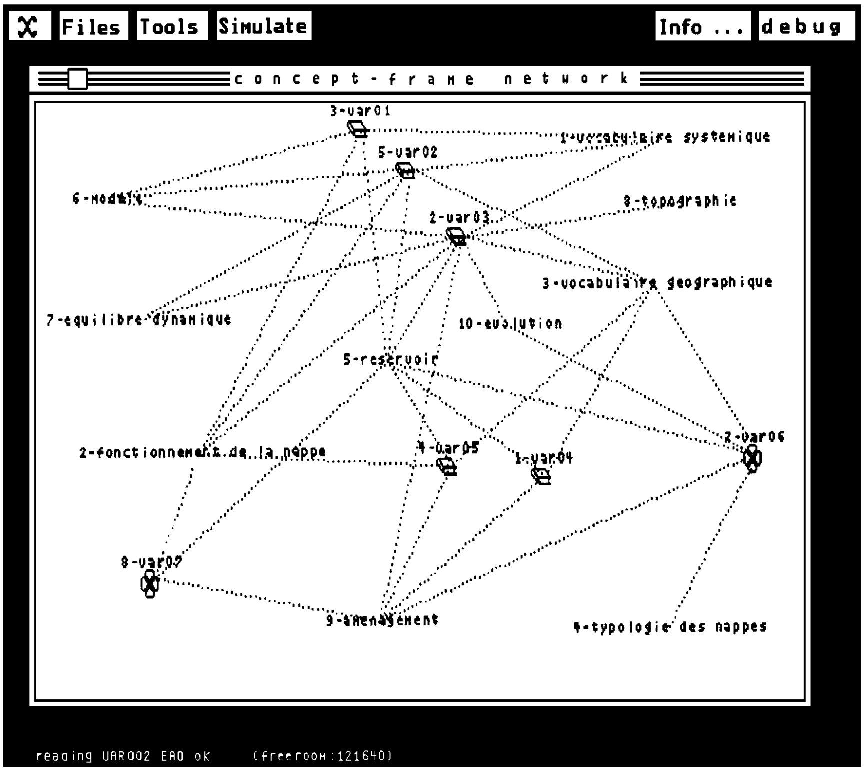
The construction of the description of the procedure followed in order to define a teaching unit can be illustrated by the case of VAR001. The goal of this teaching unit is to indicate the relationships and elements which contribute to an explanation of how a simple ground water model functions. In the light of rule ß1, the following items were selected as descriptors:

water supply, drainage, alluvial ground water table,
infiltration, springs, causal relations, model.

In the light of rule ß2, the following new list of concepts was created:

the functioning of the water ground table, systems
vocabulary, reservoir, model.

The item "functioning of the water ground table" substitutes the following set of descriptors: infiltration, supply, spring, outflow; the item "reservoir" substitutes the descriptor alluvial ground water table; and the item "systems vocabulary" substitutes: causal relation, model. However, the descriptor "model" is kept because it constitutes the main goal of the teaching unit.



The teaching units/descriptors bipartite graph.

Figure 3.

In a first specification of the VAR0 teaching unit, the incidence matrix generated by ECAL (fig.4), which determines the semantic network[4], shows several interesting characteristics. Two important ones are:

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[4] Two descriptors are related if they are attached to a same teaching unit.

• The high degree of connectivity: 40 edges are achieved out of a possible total of 45 (fig.5).

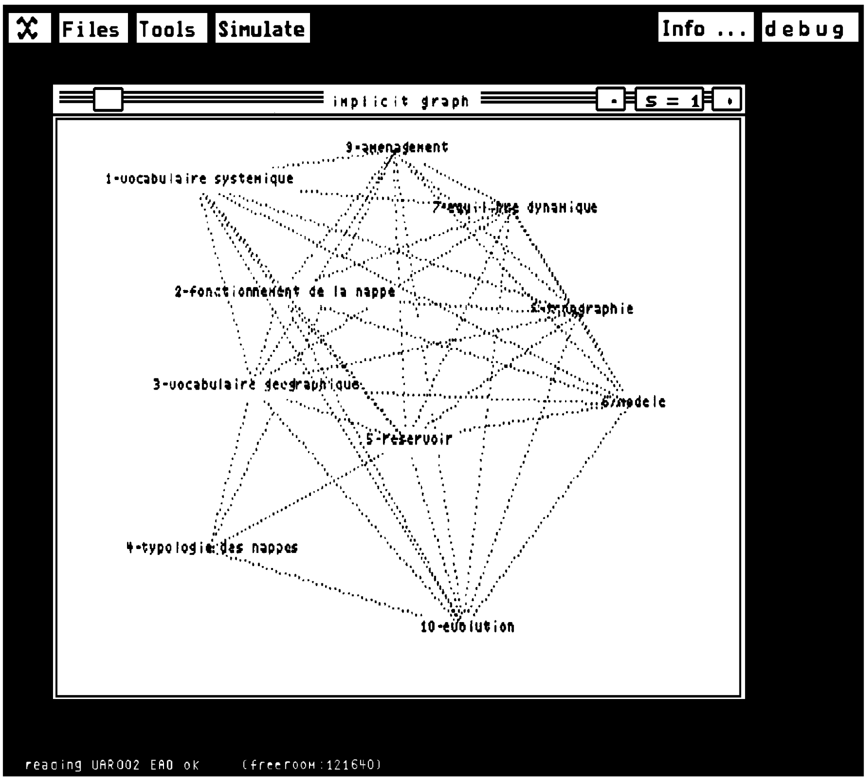
• The descriptor "reservoir" which is the main descriptor following the ECAL model would be the entrance point into VAR0, since this descriptor is used in every teaching unit (fig.2). Then, this would lead to deal with the only teaching unit associated with the descriptor "typology of ground water tables", whereas in order to deal with this descriptor one is supposed to know well the whole notion which is the target of VAR0.

It means that the specification of the teaching units cannot be done by the authors regardless of an insight of what could be its description by ECAL and regardless the strategy the tutoring system would use.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1. Vocabulaire systémique	–3	2	0	3	3	2	1	1	1	
2. Fonctionnement de la nappe	3–	3	0	5	3	2	1	3	1	
3. Vocabulaire géographique	23	–	1	5	2	2	1	4	2	
4. Typologie des nappes	00	1	–	1	0	0	0	1	1	
5. Réservoir	35	5	1	–	3	2	1	5	2	
6. Modèle	33	2	0	3	–	2	1	1	1	
7. Equilibre dynamique	22	2	0	2	2	–	1	1	1	
8. Topographie	11	1	0	1	1	1	–	1	1	
9. Aménagement	13	4	1	5	1	1	1	–	2	
10. Evolution	11	2	1	2	1	1	1	2	–	

Incidence matrix of the weighted semantic network generated by ECAL.

Figure 4.



The semantic network generated by the naïve approach.

Figure 5.

3.2.3. Second attempt: the relationship between the geographic and the systems approach.

The difficulties which where experienced with the first attempt led on to a reorganization of the teaching material. This was done by making a clear distinction between the behaviour of the alluvial ground water system, and the organization of the geographic knowledge. Finally, it was necessary te redefine the qualification rules for the teaching units using only the descriptors which enable a valid processing by ECAL likely to take place.

Consequently, the specification of SHIVA-géographe requires the construction of the relationships between the three different levels of description:

- the systems level which deals with the functioning of the ground water table;
- the descriptive level which accounts for the organization of information concerning the functioning of the ground water table; and
- the ECAL level, which organizes the information from the local descriptions of the teaching units. This organization is determined by the characteristics of ECAL and by the decisions taken in order to determine and to describe the teaching units.

3.2.3.1. Organization of knowledge: "the ground water table point of view".

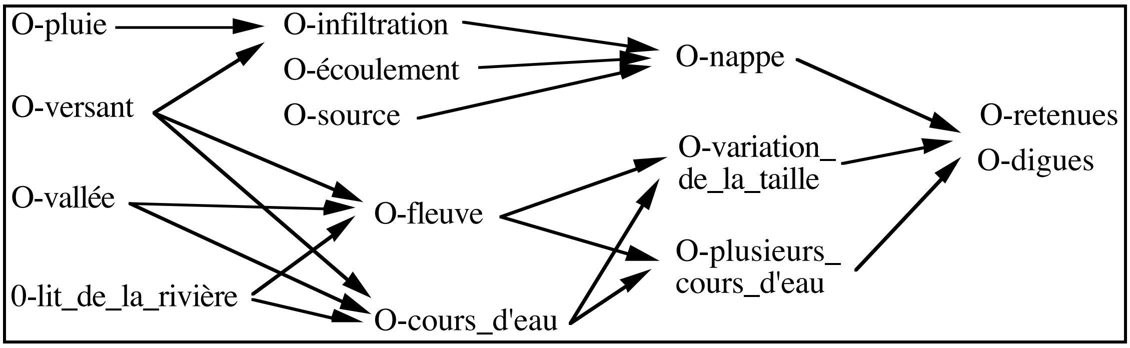
Describing the functioning of the alluvial ground water system provides an organization of the information wherein the semantics are closely related with the aims or with the practical aims of the authors. Four description levels have to be considered: (1) the level of common sense, (2) the level of descriptive geography, (3) the level of the systems analysis, and (4) the *didactical* level. The latter functions as a bridge between the level of common sense and those of the geographer and the systems analysis, it is used in textbooks and didactical discourse. The systems level is taken to be the "highest" level of conceptualisation.

Figure 6 illustrates the association between the terms from these four different lexical registers (of course, it is only a partial table). It allows to record that a few terms are common to several of them, however we cannot consider that they have the same meaning in each of these registers. We also notice that the same term in one register may correspond with several different terms in other registers. Finally, we point out a hierarchy of the registers, the highest level being that of the systemician. So concepts belonging to one level are gathered in a unifying conceptualization of the highest level. In order to separate the homonymous, we begin the terms of a specified lexical register by a prefix letter corresponding to the register they belong to (O for the "observer in the common sense, everyday language..."; G for the geographer; S for the "systemician"; D for the *didacticien*). In this way, we will differenciate O-infiltration and G-infiltration, according to whether we consider the word "infiltration" in the register of the common sense or in the register of the geographer.

Locuteur	**Champ lexical**				
Observateur (sens commun)	O-écoulement	O-infiltration	O-pluie	O-lit de la rivière	O-digue
Géographe	G-écoulement	G-infiltration	G-précipitation	G-lit_mineur	G-aménagement
Systémicien	S-flux_de_ sortie	S-flux_ d'entrée	S-fonction_ du temps		S-variable_ intermédiaire
Didacticien	D-vidage	D-alimentation _de_la_nappe	D-alimentation _des_eaux _infiltrées	D-lit_mineur	D-aménagement

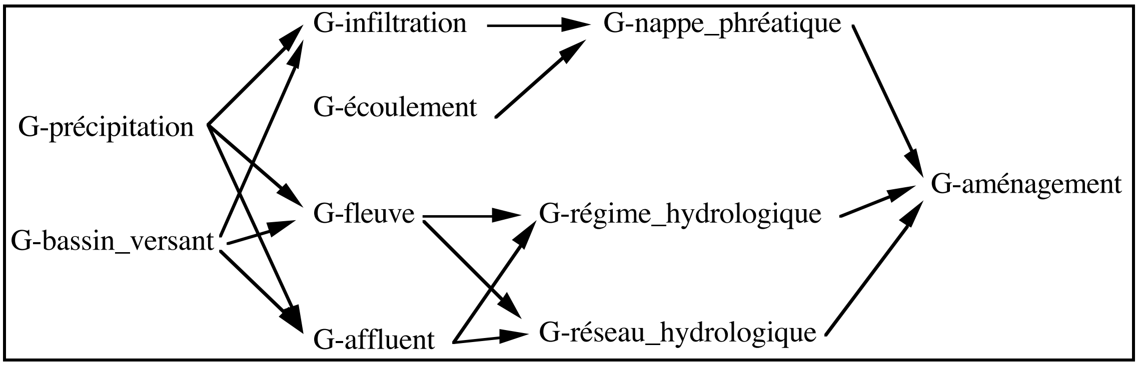
Figure 6.

For every register it corresponds a different organization of knowledge with respect to the functioning of the ground water table (graphs 7, 8 and 9). We can understand the arrows as an indication of the reading "direction" indicating a relation of dependance which is not entirely formalized.



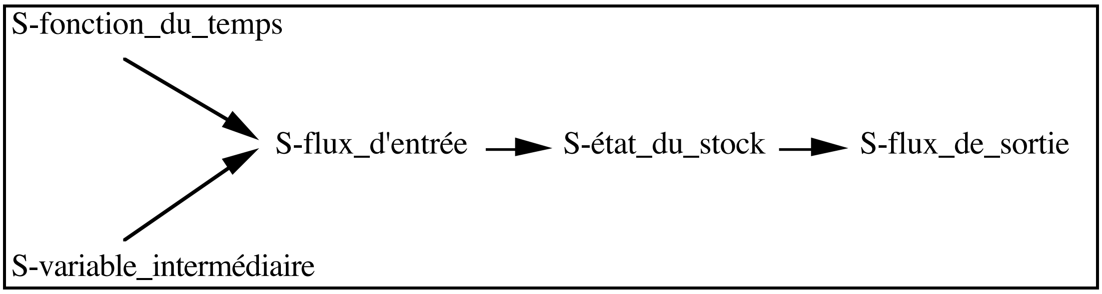
The commons sense register

Figure 7.



The geographic register

Figure 8.



The systems register

Figure 9.

We may point out that a graph which shows the structuration of knowledge would suggest an organization of the content to be taught. Thus, for instance, the knowledge about the notion of infiltration would be prior to the knowledge concerning the ground water table. But, it could mean that we ignore that the relevance of the geographical concept of infiltration is based on its problematization in the study of the functioning of the ground water table.

Consequently, we must conclude that it is not possible to confuse the organization of knowledge, even when modelling a particular phenomenon, with its relevant organization for teaching purposes. The latter also includes feedbacks loop and so this is the justification for using a systems approach. Returning to the case study of SHIVA-géographe, conceptualizing the alluvial ground water table leads to the question of water supply and this in turn leads to questions of the role and function of infiltrations which may lead, via feedback loops, to questions about the supply of water to the ground water table which may finally lead to some restructuring, for example in order to give account of the snow retention and snow melt factors in the upper basin of the river Var.

3.2.4.2. The organization of knowledge, "the descriptive approach".

In geography, as an academic discipline, knowledge is organized in a hierarchical way, with levels which enable a distinction to be made between language and metalanguage, phenomena and categories of observation. This organization can be made explicit by a tree structure. In the case of the ground water table, the main branches of this structure correspond to the main topics in the domain considered and consists of: geology, pluviometry, topography, hydrology, study of the ground water table, town and country planning. The elements which compose these topics are organized hierarchically according to the logic of the discipline. For instance:

(geography (

topographical study (

cross section (water bed (mean water bed) (high water bed)))))

Since in our study the geographer's point of view includes the systemician's one, we use the systems register in order to propose a re-organization of this point of view, not for a description of the functioning of the ground water table, but for the structuration it allows of the concepts used in geography. The discussion on the role of systems analysis in geography teaching or research is an epistemological discussion we do not wish to tackle here.

3.2.4. The ECAL semantic network

The learning targets are here expressed with the terms of descriptive geography, with respect to the conceptual organization of geography as a discipline, we have adopted the following rules:

• ∂1: if a particular concept is studied in a teaching unit, then, the name of this concept is taken as a descriptor.

• ∂2: if all the descriptors dependant on the same node of the tree are used, then the descriptor corresponding to this node is also attached to the teaching unit.

• ∂3: if a subset of descriptors which is linked with the teaching unit forms also a sub-tree, then this subset is substituted by name of the root of the sub-tree.

In the case of the teaching unit VAR004, these rules give the following result: "G-hydrographical _network" is kept as relevant descriptor for this teaching unit because the first descriptors of this unit were "G-tributaries" and "G-river" which imply "G-stream_of_water " and thus "G-hydrological_network". If the description would have lead in choosing also "G-hydrological_regime", then "G-hydrological_regime" would have been a descriptor of this teaching unit.

3.3 ECAL CONSTRAINTS AND THE CONTROL OF INTERACTION

The VAR0 subset of the SHIVA-géographe teaching units consists of 7 elements, we present them here after in a non-formal way along with the list of descriptors.

VAR001: a "causal graph" which brings out the relationships and system elements used to explain the way a ground water table works.

Descriptors > G-state_of_ground_water_table, S-storage

VAR002: the bathtub metaphor, which introduces the concept of dynamic equilibrium and initiates learners into systems vocabulary.

Descriptors > O-variation_in_head, S-flow_trajectory, G- ground_ water_table_flow_regime.

VAR003: a block diagram, for the acquisition of vocabulary related to relief and engineering works, block diagram interpretation.

Descriptors > G-topographical analysis, S-variation_in_head, G-ground_water_table_flow_regime.

VAR004: the lower Var basin hydrographical network, reminds learners of the main features of a hydrographical network, location map interpretation.

Descriptors > G-hydrographical_network, G-catchment_area, G-longtitudinal_section

VAR005: geological cross section, interpretation of cross sections and drawings of hydrogeological features

Descriptors > G-longitudinal_section, G-cross_section, G-geological_ analysis.

VAR006: ground water table type, ground water table classification (ground water table, alluvium, deep, etc.)

Descriptors > G-geological_analysis, G-analysis_of engineering_ works, G-ground_water_table_classification.

VAR007: piezometer recordings, bringing out the difference in geographical meaning between head and volume in an aquifer classification (ground water table, alluvium, deep, etc.)

Descriptors > G-state_of_ground_water_table.

For purposes of illustration let us look at the way in which the list of descriptors for VAR001 is built up. By applying rule $\partial 1$ the authors suggest the following initial list:

{G-infiltration, G-flow, S-output, S-input}.

The application of $\partial 2$ gives:

{G-infiltration, G-flow, S-output, S-input, G-state_of_ground_water_table,S-storage}

Lastly, rule $\partial 3$ gives:

{G-state_of_ground_water_table, S-storage}

since each of these descriptors is located at the root of a sub-tree which is exhaustively described once.

unités pédagogiques de VAR0 …	**01**	**02**	**03**	**04**	**05**	**06**	**07**
descripteurs :							
G-état_de_la_nappe	X						X
S-état_du_stock	X						
O-variation_de_la_ hauteur_d'eau		X	X				
S-trajectoire du stock		X	X				
G-régime_de_la_nappe		X	X				
G-étude_topographique			X				
G-étude_des_aménagements			X			X	
G-réseau_hydrographique				X			
G-zone_drainée				X			
G-coupe_longitudinale				X	X		
G-coupe_transversale					X		
G-étude_géologique					X	X	
G-typologie_des_nappes						X	

Enhanced approach: description of the teaching units by descriptors

Figure 10.

The adjacency matrix of the teaching units/descriptors bi-partite graph (figure 10) and the matrix of the weighted semantic network derived by ECAL (figure 11) will be associated with the above description of VAR0 while a number of specific indices will also be computed by ECAL. A diagram showing the ECAL semantic network at the system interface is given by figure 12.

	1	2	3	4	5	6	7	8	9	10	11	12	13
1 G-état_de_la_nappe	-	1	0	0	0	0	0	0	0	0	0	0	0
2 S-état_du_stock	1	-	0	0	0	0	0	0	0	0	0	0	0
3 O-variation_de_ la_hauteur_d'eau	0	0	-	2	2	1	1	0	0	0	0	0	0
4 S-trajectoire du stock	0	0	2	-	2	1	1	0	0	0	0	0	0
5 G-régime_de_la_nappe	0	0	2	2	-	1	1	0	0	0	0	0	0
6 G-étude_topographique	0	0	1	1	1	-	1	0	0	0	0	0	0
7 G-étude_des_aménagements	0	0	1	1	1	1	-	0	0	0	0	1	1
8 G-réseau_hydrographique	0	0	0	0	0	0	0	-	1	1	0	0	0
9 G-zone_drainée	0	0	0	0	0	0	0	1	-	1	0	0	0
10 G-coupe_longitudinale	0	0	0	0	0	0	0	1	1	-	1	1	0
11 G-coupe_transversale	0	0	0	0	0	0	0	0	0	1	-	1	0
12 G-étude_géologique	0	0	0	0	0	0	1	0	0	1	1	-	1
13 G-typologie des nappes	0	0	0	0	0	0	1	0	0	0	0	1	-

The adjacency matrix of the ECAL semantic network.

Figure 11.

The order in which the teaching units are numbered originally corresponded to the authors' ideas concerning the relevant order of presentation. The aim of unit VAR001 is to broadly introduce the way in which an alluvial ground water table works. With the help of the bathtub metaphor VAR002 introduces and links up the linguistic registers of the geographer, the systems analysis and the everyday language. Units VAR003 to VAR005 use "representations of geographical reality" to go over and hone the concepts brought in by VAR002. VAR006 enriches the ground water table concept by pointing out the variety of ground water tables which exist. Lastly, VAR007 consists of a specific teaching unit which shows the relevance of the head variable, rather than the water volume variable to which common sense considerations would tend to give preference.

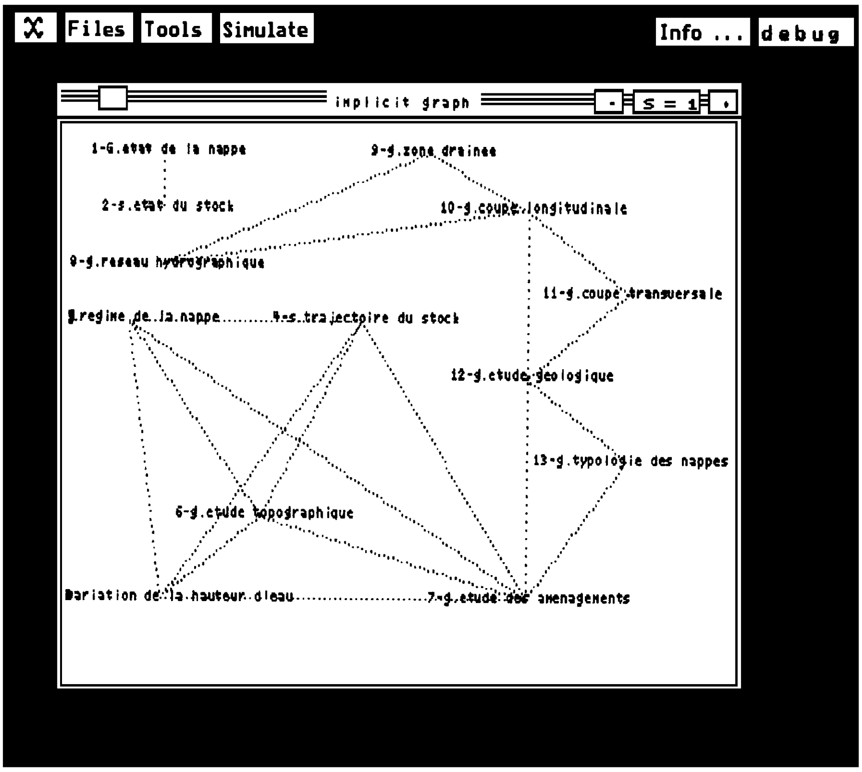


Figure 12.

This description actually brings out a partial ordering of the sequences rather than the total ordering implied by the numbering. This order would appear to be as follows:

- (i) VAR001 or VAR002
- (ii) VAR003 or VAR004 or VAR005
- (iii) VAR006 or VAR007

The sequence computed by ECAL is now analysed with respect to the explicit expectation of the authors. The order in which ECAL presents the units, as taken from the implicit graph, is as follows

VAR002, VAR003, VAR006, VAR005, VAR004, VAR007, VAR001.

The authors were surprised by this order. But to be fair, from their point of view this order is deemed to be acceptable, although it is clearly not possible to generalise this judgement to the acceptability of any of the ECAL computations. For one reason, there are clearly important differences, and for another the acceptability of the ordering may arise from the fact that the set of VAR0 units is fairly homogeneous both in terms of a didactical analysis and of a geographical analysis: it seeks to introduce the concept of dynamic equilibrium of the water table. So, we shall look more closely at the differences which have arisen, at least at the more significant ones.

Unit VAR006 is suggested by ECAL much earlier than envisaged by the authors. Unit VAR001, on the other hand, goes from first to last position. In order to analyse the reasons for these modifications we must look at the sequence of "main focus" worked out by ECAL:

O-variation_in_head
G-analysis_of_engineering_works
G-geological_analysis
G-longtitudinal_section
G-state_of_water_table.

The fact that VAR006 has moved up in the list is due to its descriptor, G-analysis_of_engineering_works, which is heavily weighted. This weighting is because unit VAR003, which it describes, is also described by a number of other descriptors. We see then that the number of descriptors corresponding to a teaching unit can have a considerable effect on the importance of the descriptors; following ECAL if a teaching unit has n descriptors, then the importance of each is at least n-1.

So, if a unit deals with a large number of concepts (n), this very fact means that they will be ascribed a high degree of importance (n-1), even though these concepts may be used only sparingly. Rule ∂3 can limit this effect, but it is only applicable when the descriptors in question form a sub-tree within the descriptor tree. This will is not the case if the unit deals with a heterogeneous set of notions with respect to the reference structure.

The move of VAR001 from first to last position results from a phenomenon of a different nature. The implicit graph is not connected (see fig. 12) and the ECAL procedure is such that it only changes components once all the descriptors of the current component have been dealt with. Moreover, if a component's generality is defined by the maximum generality of the elements which compose it, ECAL will process the connected components of the semantic network in decreasing order of generality.

The question at issue here is whether or not the existence of several connected components is of epistemological importance and therefore of any didactical relevance too. At first glance, this would mean that there exists a partition of the set of descriptors into sub-sets which are independent as far as conceptual relationships are concerned. This is not the case here: it is impossible to assume that the G-state_of_water_table and G-ground_water_table_flow_regime descriptors are independent of one another. The overall, non-connectivity of the graph is in fact the unintended effect of a decision which was taken locally in order to describe a teaching unit. An *ad hoc* modification of this state, that is the insertion of a unit providing a link between two components, could provoke the generation of an ECAL sequence in an inappropriate manner. We carried out such a procedure by creating a fictitious unit VAR008 with descriptors G-state_of_water_table and G-ground_water_table_flow_regime (see figures 13 et 14). The succession of units generated by ECAL was then the following:

VAR008,VAR002,VAR003,VAR006,VAR005,VAR04,VAR007,VAR001.

This sequence corresponds to the following sequence of "main focus":

G-ground_water_table_flow_regime

G-analysis_of_engineering_works

G-geological_analysis

S-longtitudinal_section

G-state_of_water_table

We see here that one of the descriptors, which was eliminated by the initial non-connectivity of the implicit graph, appears in this new configuration among the "main focus" considered by ECAL. Furthermore, the unit which was added in an *ad hoc* manner has now been promoted to first place, whereas the rest of the sequence remains unchanged. We will not take analysis of this fictitious situation any further for now. Nevertheless, it is possible to pick out the two main stumbling blocks which the authors encountered: on the one hand, the lack of elements for an a priori evaluation of the relevance of the decisions which will be taken by ECAL and, on the other hand, the lack of means to interpret ECAL's decisions with respect to the specific aims of the teaching envisaged.

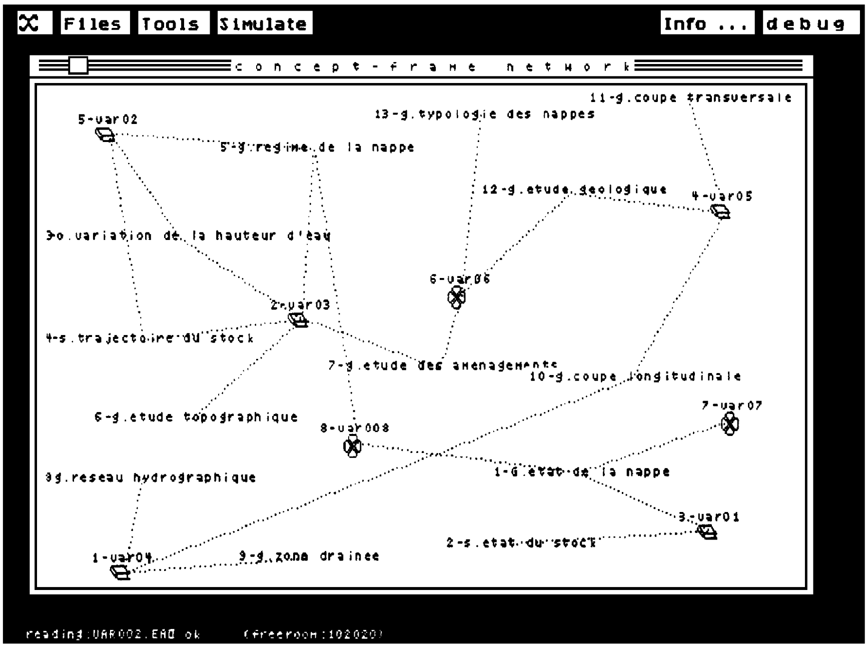


Figure 13.

We need then to provide authors with the means to judge the significance of the connectivity or non-connectivity of the ECAL semantic network which results from the choice of descriptors they made. At least, one must of course be in a position to test the connectivity of the graph.

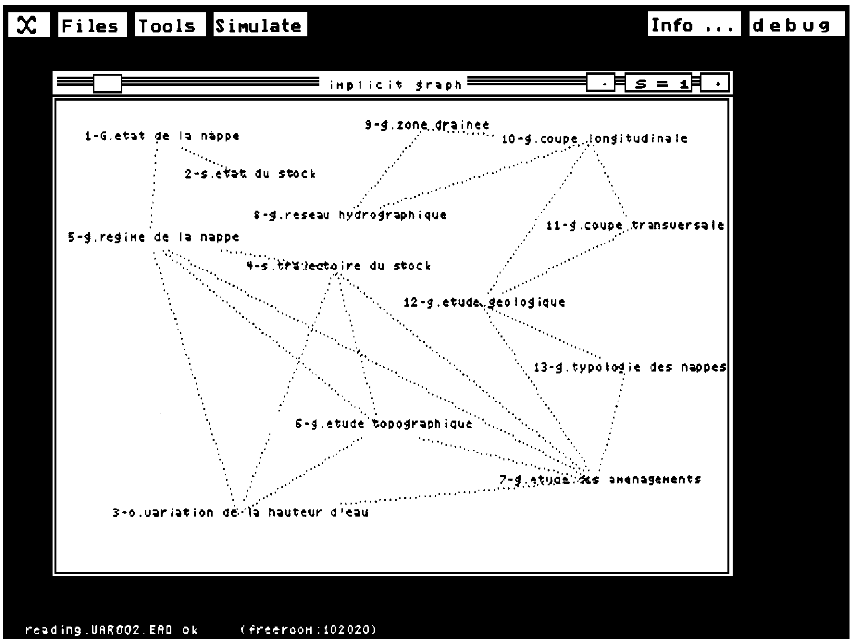


Figure 14.

4 CONCLUSIONS

One of the first results of this project carried in a domain which is both complex and highly specific is the crucial nature of the relationship between the author's locally taken decisions and their consequences at the overall level. The issue of the connectivity of the ECAL semantic network is an example of this. Once we get beyond a certain threshold of complexity (which we believe to be quite low-level) it is impossible for the author to control in a simple manner the effects of his choices. This problem will probably not therefore be solved in terms of navigation possibilities through the network which is represented graphically at the system interface.

The problem could perhaps be eliminated by providing the author with an operational way of representing the structure and capabilities of the system. The mere description of the authorware's functions or those of the ECAL computational procedures are not enough. We had this information and it was not sufficient to enable the didactical process to be controlled. Consequently, it was not possible to control the learning outcome which might result from its use.

So, the principles which could enable the authors to anticipate the outcomes of their decisions and their implication with respect to the achievement of teaching aims should be defined. For instance, one of these principles could be determined for the number of descriptors in a teaching unit, and thus for criteria concerning size and homogeneity in terms of the knowledge at issue.

A further result is that we now have an experimental method for specifying relationships between learning analysis as perceived by geographers and that of ECAL. A research log book would enable a record of the authors' conjectures to be systematically compared with the results of evaluations. The formulation of such conjectures will necessitate, on the one hand, the statement of their theoretical foundation and, on the other hand, the statements concerning the existence and the nature of the events to be considered as data for the evaluation. An analysis of the simulations generated by SHIVA-géographe and its critical comparison with the a priori analysis will enable specification principles to be defined in this environment. This will provide a means for evaluating the courseware production workshop itself. The analysis described above, together with the presentation and the study of the authors' first attempts, constitute an example of this approach.

(translated in English by R. Bradshaw, Jim Brougham and H. Chamussy)

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