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ABSTRACT

This report described and analyzed different methods for constructing a student's cognitive map in order to study the development and use of domain-specific prior knowledge. Cognitive maps provide accounts of student trajectories over courses and individual or group profiles of learners' strengths and weaknesses at the course or multicourse level. Methods are grouped into: (1) clinical interviews with individual students; (2) word-association or word-sorting tasks (including free recall); (3) writing methods (e.g., writing definitions or choosing preferred statements); (4) bipolar dimension tasks; and (5) think-aloud methods, such as verbal protocols. The free recall (word association) method is considered most appropriate for the planned research. Two figures illustrate the concepts discussed. (Contains 32 references.) (SLD)

Methods for Investigating the Structure of the Individual's Knowledge Base

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- the developments of the "Computer Assisted Testing"-project;
- the developments of "Adaptive Testing" and the IRT-applications (Item-Responds Theory); and
- the experience of the Open University with the development and use of TSS (Test service systems).

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Introduction

Earlier we stated that there is a renewed interest in schema theories and that prior knowledge plays a central role in all of these theories (Dochy, 1992). What a learner already knows provides a framework for new knowledge and it is the starting point for the construction of a representation of the cognitive structure. An advantage of cognitive structures is that they give the possibility to interpret complex phenomena like information - processing.
In this article, we will describe and analyze different methods for constructing a student's cognitive map in order to study the development and the use of the domainspecific prior knowledge. In literature, the comparison of different cognitive structures or maps is seen as a fundamental method to investigate student learning. Such reference maps provide accounts of student trajectories over courses and individual or group profiles of learners' strengths and weaknesses at the course or multicourse level (Snow, 1990).

1. Cognitive Structure

Being able to represent knowledge is a key of being able to utilize it. Knowledge and skills have been represented in educational literature in three kinds of representations: cognitive, content, and curriculum structures.

Ausubel's (1968) definition of cognitive structure is: an individual's structure of knowledge (the sorts of knowledge people have and how they store it). Representation is defined as the external organization of knowledge in a structure. Cognitive structures allow information to be traced and located quickly. A schema of concepts and relationships acts as a unit of memory.

Representations of cognitive structure have three characteristics (Donald, 1987):
* a representation reflects the method of analysis used to produce it, i.e. one must analyze a schema into its component parts, relationships, and organizing structure in order to represent it. The kinds of representations that exist in the research literature can be categorized according to the methods used to produce them and the assumptions governing those methods;

* the representations and the methods used to produce them assume differing amounts of structure in the universe. This range of assumptions of structure is a prominent dimension in the comparison of disciplines (i.e. a distinguish between hard (e.g. scientific theory) and soft disciplines on the basis whether a paradigm or theoretical structure exists, or whether content and method are idiosyncratic in the discipline).
* the degree to which the representations of cognitive structure are descriptive (i.e. they do not include transformations or changes in state) versus goal oriented.

Cognitive structure is extensive and n-dimensional. Any attempt at description can only hope to illuminate part of this whole. The n-dimensionality inevitably leads to a trade-off between the extent and the detail of the description.

Cognitive structure has two components: the knowledge bits it contains, and how that knowledge is organized. Knowledge bits (propositions (=representations in memory of facts or beliefs), algorithms (or skills), images (=mental pictures), a person's private understanding of the meaning of words) can be quite different in size and nature.
The cognitive structure of experts consists of a knowledge-repertoire (= organisation in the memory from problem-situations, declarative and procedural knowledge) that is build up by problemschema (= representations made for educational purposes; such a schema should be precise, coherent, and consistent) or it has been hierarchical organised (Dochy, 1992).
Beginners often lack the hierarchical and problem oriented structure. According to Reif (1983) it is important to learn these kind of structures.
Three aspects of the structure of knowledge determine the ability of the student to learn:

* internal integration (= the degree to which different parts of subject matter are interrelated with one another and not isolated).

- connection (= the degree to which subject matter parts and concepts are connected with the prior knowledge)
- correspondence (= the degree to which students' cognitive structure corresponds with the experts' cognitive structure in a certain domain).

The proposed dimensions of cognitive structure are based on the Gagné and White model. This is a static model, in which there are four sorts of elements: propositions, intellectual skills, images, and episodes. The dimensions are the following:

1. extent: how much knows a person;
2. precision of the knowledge: how precisely can he/she formulate his/her knowledge;
3. internal consistency: are all parts of knowledge compatible;
4. accord with reality or generally accepted truth: are there differences between knowledge and reality;
5. variety of types of element: is there imbalance between the verbal knowledge of a person and his/her episodes or skills; the desirable form of cognitive structure is one of a good mixture of types of elements;
6. variety of topics: one might, e.g., distinguish between people who are specialized in knowledge of a small number of fields and generalists who have some knowledge of many topics;
7. shape: the form of organization of cognitive structure. If we think of knowledge as a network of elements, of whatever types, we can conceive of networks having different shapes and degrees of interlinking; shape could be represented for some purposes by an index called association density, the average number of associations per element;
8. ratio of internal to external associations: the proportion of elements in a chain or net which are internal, in the sense of obviously being parts of the subject matter, and the proportion which is external, or unessential parts which illustrate the topic (rather than to form a vital part of it);
9. availability (of knowledge): two people may know the same things, but differ in the ease with which they recall relevant elements at need.

These nine constructs, and the practical measures of them (e.g., shape could be represented by an index called association density, the average number of associations per element), are not necessarily independent of each other. The intent here is to propose a number of constructs which may be useful in describing cognitive structure.
Earlier we stated that we found a general agreement among experts and in literature that cognitive structure provides mostly information on the availability of prior knowledge (which can be differentiated into constructs 3,4,7 and 8: internal consistency, accord with reality, shape and ratio of internal to external associations).

The most commonly accepted model of cognitive structures in long-term memory is an associative network model (e.g., Anderson, 1976, 1983, in: Martin, 1985)). A network consists of a set of nodes or points interconnected by a set of lines or arcs. Within this model, the nodes of the network represent concepts, and the lines are links among the concepts (Dochy and Bouwens, 1990). The links may vary in strength, resulting in some concepts being more strongly associated than others. Long-term memory is hypothesized to consist of an enormous number of such networks or structures that themselves are linked together in higher-order configurations, perhaps in some sort of hierarchical manner.
Figure 1 represents a portion of the cognitive structure of a medical student that centres around the concept of hart-attack.
Information is retrieved from an associative network through spreading activation. Specific nodes of the network are activated, and the activation then spreads through linked nodes.

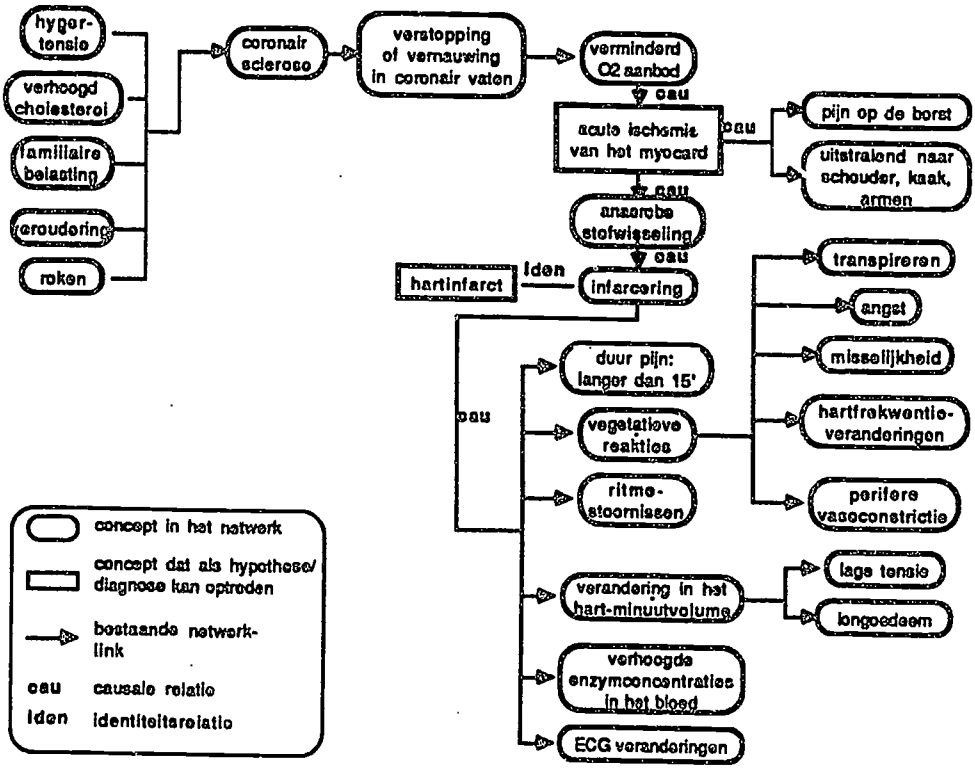

Figure 1: Example of a network structure: a part of a medical students' knowledge concerning 'hart-attack' (Adapted from Boshuizen, 1989).

2. Methods for Recording Cognitive Structure

Several techniques/methods have been used in attempts to probe the learner's structure of knowledge. We group these methods into 5 categories:

1.) Clinical interviews with individual students;
2.) Word-association or word-sorting tasks;
3.) Writing methods, i.e. asking learners to write definitions, or to choose a preferred statement from several correct ones;
4.) Bipolar dimension tasks, i.e. tasks which involve bipolar dimensions on which an idea is rated;
5.) Think aloud methods, i.e. verbal reports (protocols).

These categories of techniques will be discussed in the following paragraphs. In describing these, we will try as far as possible to take account of the criteria which should be specified for any valid method for assessing cognitive structure (Shavelson, 1974; in: Jonassen, 1987): the stimuli used to examine cognitive

structure; the instructions to subjects; the context in which the measurement takes place; the nature of the subject's response.

2.1. Clinical Interviews

These techniques were originally used in clinical psychology.
Piaget (1929) described the essence of the method as follows: "the clinical examination is dependent on direct observations, the practitioner lets himself be led, and takes account of the whole of the mental context".

The clinical interview method, as originally used by Piaget, takes two formes: verbal and revised. The verbal clinical method involves flexible questioning of individual children on a totally verbal level; concrete objects do not serve to illustrate or represent the problem posed by the interview.

Example provided by Gelman (1980, p. 65; in: Ginsburg)

I: What's the biggest number you can think of?
S: A billion.
I: Is that the biggest number?
S: No.
I: What is?
S: I don't know.
I: Why don't you know?
S: Numbers never end.
I: What if somebody told you that a googol is the biggest number?
S: I'd say that numbers never end.
I: Could you prove it?
S: No.
I: What if you add 1 to a googol?
S: A googol and 1.

In the revised clinical method, the data of interest are both verbalizations and aspects of nonverbal behaviour. Piaget attempted to improve the verbal method by using concrete objects to illustrate the problem to be solved.
The classical example is the observation of numbers, as described by Piaget and Szeminska (1952):

Hab (5:3) began by putting 9 sweets opposite the 6 of the model, but made the row the same length. That's it --Are they the same?--I'm not sure. --Where are there more?--There throw of 9, close together)--What must we do then?--(She put 6 opposite 6 of the model and removed the rest)--The 6 of the model were then closed up)--Are they the same?--No.--Are there as many here (model) as there?--No, there (copy) there are more--Is there more to eat on one side than on the other, or are both the same?--I shall have more to eat.--Make them both the same, then --(She removed 2. then made the one-one correspondence, and finally put the two back when she found they were missing!) [p.79]

Piaget developed the clinical method in order to achieve three aims central to the study of cognitive development:

1. the elicitation of intellectual activities;
2. the specification of the nature and organization of cognitive processes;
3. the evaluation of the child's level of cognitive competence.

Ad.1.) The clinical method attempts to give children the opportunity to engage in various intellectual activities, like the speculation on the origins of the sun.

Ad.2.) Once relevant intellectual activities have been elicited, the cognitive processes underlying them need to be examined in detail and described as precisely as possible. Piaget usually describes these processes in

terms of the "structures" of intelligence, general mental capacities presumably underlying performance on a wide range of tasks.

Note that elicitation of intellectual activities and specification of cognitive processes operate at several levels of specificity. The beginning stages of research may be said to involve discovery: our knowledge of cognition is so limited that it is necessary to begin most research investigations with the aim of discovering relevant phenomena and processes. Next the investigator wishes to go beyond the discovery stage to obtain further empirical data of interest and to develop precise descriptions of cognitive processes: specification. Furthermore, discovery and specification appear to be cyclical processes (discovery → specification → discovery → specification → etc.).

Ad.3.) Piaget's theory aims at establishing underlying competence -the child's highest ability at this current stage of development- and does not often deal with typical performance -the child's ordinary behaviour on a particular occasion.

The investigation of competence focuses on three areas: subjective equivalence (the child understands the question in the way it is intended), seriousness of response (the child takes the task seriously), and strength of belief (the child's response is deeply held).

A related and more recent approach or method, until now based on interviews, was developed in Mölndal, Sweden at Gothenburg University. This 'phenomenographic' approach offers techniques for systematic interviewing or recording of student structuring. This phenomenography of learning, still under development, is an approach to describing learning as a change between qualitatively different conceptions based on students' cognitive structures (Johansson, Marton &Svensson, 1985; Marton, 1987; Marton, 1988; Kroksmark, 1990). Although intensive interviewing may often be uneconomical, some of these procedures can be used selectively, some may be computerized in future (Snow, 1990).

2.2. Word-association tasks

A method for assessing cognitive structure is to generate a map of it, i.e., a cognitive map (Jonassen, 1987). The techniques available for mapping cognitive structure are all based upon the concept of semantic proximity of words or constructs. That is, the more proximate words are to each other in an individual's cognitive structure, the more semantically related they are. This notion of proximity assumes that we can represent knowledge in terms of geometric space, that is, map knowledge structures.
Cognitive maps are produced from behavioral measurements and interpreted as abstract representations of one's knowledge of some subject matter structure (Shavelson, 1985). It is based upon an associative network theory of long term memory.
Preece (1976) compared the three most prominent methods for mapping cognitive structure:

(1) free word association/ free recall, i.e. a paired association task using the same stimulus word repeatedly;

(2) controlled word association; this requires the learner to associate words in rank of order of importance. Preece generated relatedness coefficients (measures of overlap between two word association hierarchies) for each pair of words in the same content domain;

(3) tree construction tests; this requires learners to construct a linear graph (tree) in which the vertices (intersections) are the words and the connecting lines the relationships. The two most closely related key concepts, according to the learner, are linked with a line numbered one. Then the key concept most closely linked to either of these was chosen and linked with a second line. The learner proceeded until all key concepts had been placed in relation to the others. The resulting tree structure displayed the closest relationships between key concepts in order.

With the word-association / Free-response method (Shavelson, 1974), the subject is shown a stimulus word and asked to respond with the first word or all the words he can think of. The raw data, then, are the subject's list of responses to each stimulus word in the test.

Example provided by Shavelson (ref.14, p.41):

This is a test to see how many words you can think of and write down in a short time.
You will be given a key word which represents a concept in "physics", and you are to write down as many other words as you can which the key word brings to mind as you can. You will probably not be able to fill in all of the spaces on a page, but do the best you can. Be sure to think of the key word after each word you write down, because the test is to see how many other words the key word makes you think of.
For example, suppose I asked an electrician to write down as many words relating to electricity (his speciality) as he could think of when given the word "Conductor".

He might put down the following:

Conductor

Conductor ___*metal*___
Conductor ___*resistor*___
Conductor ___*charge*___
Conductor _____
Conductor ___*transmit*___
Conductor _____

You will notice that as an electrician, he did not put "train" or "cable car" or "guide", since they do not relate to the electrical concept of "conductor". In this same way, you should think like a physicist when you respond to the concepts. You will have one minute on each page. I will tell you when to go to the next page.

From these data, a number of different scores are commonly derived:

a. the total number of responses to a stimulus word;
b. the average number of responses to the stimulus words;
c. the number of responses of a particular kind in the responds list (e.g., only responds words that constitute concepts in an equation defining the stimulus word);
d. the overlap of responses lists for pairs of concepts.

The number, kind, and order of responses in the list, and the overlap of response lists, take on particular importance in interpreting word association data. They are used to make inferences about cognitive structure with the acknowledgement that the structure is not necessarily represented in its complete form or without some distortion.
Two disadvantages of this method are (Hirschman,1982) that:

1.) the data provide no information on the nature of the association, and in particular, on the positional relationship of an evoked response to the stimulus;
2.) the stimulus list has to be developed a priori and assumed to form a specific hierarchy.

In the graph construction method (Shavelson, 1974), respondents are given an alphabetical list of key terms (sometimes derived from word association methods) and asked to build a linear tree graph by connecting pairs of words (nodes on the graph) with a line representing the "similarity" between all pairs of words (nodes) on the graph (→ they are asked to arrange these terms in a pattern that represents relationships among them, with nodes as concepts and lines as relationships). The raw data, then, are the distances between all pairs of words (nodes) on the graph. From these "proximity" data, various scaling techniques can be used to examine the structure underlying them. With this method, the order in which words are connected by lines on the graph and the resultant proximity among words take on particular importance in examining cognitive structure.

Example

On the top of the next page is an alphabetical list of N terms. Read the list carefully several times. From the list of N terms, pick the two terms which you think are "most similar" to each other. Write the pair you have chosen in the middle of the page and connect them with a line. Label the connecting line 1.
Now you have two options as follow.
Option 1: You may go carefully over the remaining terms in the list (which now includes N-2 terms) and pick the term which you think is most similar to either of the two terms you have already selected. Write

this term down on your paper and connect it tot the appropriate term already selected. Label the connecting line 2.

Option 2: *You may look over the remaining terms on the list and decide that two of them are more similar to each other than any one of them is to either of the two terms already selected and joined together. If so, you may select these terms and write them down on the paper, just as you did with the first pair. Connect the two new with a line and label it 2.*

After taking option 1 or 2, proceed in exactly the same way. Search carefully the remaining terms on the list and continue with option 1 or 2. When you take option 1 you add a term to an already linked group of terms (which is called a tree). When you take option 2 you start as a new tree.

As you proceed, you have a third option:

Option 3: *If you find that you have made several trees, you may want to connect any two of them together. If you find two terms, on two separate trees, that are more similar to each other than any other term on the remaining list is to any other term on the trees, you should connect these terms (and thus connect the two trees). Label the connecting line according to the sequence already started.*

In short you have the following options:

1. *Adding a new term to one of the trees you have already made.*
2. *Starting a new tree with two new terms.*
3. *Connecting two separate trees.*

Please continue in this way until all N terms have been exhausted and until you have connected all separate trees into one tree. (Remember, write down each term just once. You may find it helpful to cross out the terms in the list as you write them down). When you have finished, you will have made one tree of N terms connected by N-1 numbered lines (adapted from Fillenbaum and Rapport). (ref.656, pp 15-16).

Sorting techniques require respondents to sort terms or concept labels (again typically determined from word association methods) into various categories on the basis of perceived similarity (relatedness) and dissimilarity (e.g., Shavelson, 1974).

In the card sorting method (Shavelson & Stanton, 1975) subjects receive cards with domainspecific concepts printed. Each card contains one concept. Participants are requested to sort the cards on as many stacks as they choose. Cards in each stack should have a high degree of similarity.

For each participant a matrix of similarity is to be constructed. Each combination of concepts gets a certain value, i.e. a value of 1 id both concepts are in the same stack, a value of 0 if they are not. Subsequently, the matrices of all subjects are summarized into one matrix. The maximum value of each cell will be equal to the amount of participants, the minimum value then is zero.

The concept structuring analysis technique (ConSAT) was devised by Champagne and Klopfer (1981) as a way of eliciting graphic representations of students' cognitive structure. The basic procedure of this method is not the same as the above described method. For student interviews using the ConSAT, the concepts were written on small cards, and the student was asked to identify which ones he/she recognised, and then to provide a definition for the recognized concepts. Finally, the student was asked to arrange the recognized concepts on a sheet of paper "in a way that represents how you think about the words and about the relationship between them". When the arrangement was completed, the grouped concepts were circled and the student was asked why he/she made this arrangement and to explain particular groupings. The student's answers were tape-recorded and written on the sheet containing the arrangement. The resulting cognitive structures were subsequently divided into categories of structures based on several criteria. These categories are hierarchical organised in which the top category is best integrated, systematically organised, etc.

The method used by Champagne et al. shows the disadvantage that the classification of structures involves a reasonable reduction of richness of the data. Relations between different concepts for example cannot be traced back.

2.3. Writing methods

Schaefer (Sutton, 1980) includes writing a definition as a technique in his investigations of the concepts of growth. Because the respondent has to compose a statement in his own terms, he has the opportunity to

consider all the ideas available to him about the topic. No doubt the act of composition can help to make more firm any incipient of the knowledge which is not yet well established.

Kemper and Hodgson (Sutton, 1980) used the technique of allowing the respondent to choose one definition from several all of which can be regarded as correct. This has the advantage that it is accessible to pupils who may find composing their own definition difficult, and therefore give up; and it also lends itself to quantitative processing of the results of the investigation.

Analysis of a writing protocol: Hayes and Flower (in: Gregg and Steinberg, 1980) describe a model of the writing process derived through protocol analysis (→ a protocol is a description of the activities, ordered in time, which a subject engages in while performing a task).
The unique features of the model are:

1.) it identifies not only subprocesses of the composing process, but also organization of those subprocesses;
2.) minor variations in its simple control structure allow it to describe individual differences in composing styles.

To facilitate the analysis of writing, they have divided the writer's world in three major parts (figure 2):

* the task environment, → includes everything outside the writer's skin that inferences the performance of the task (e.g.,information relevant to the writer's motivation);
* the writer's long term memory, → writers have knowledge about many topics (e.g., auto mechanics) and audiences (e.g., children);
* the writing process, → writing consists of three major processes:
  - planning (→ function: to take information from the task environment and from the long term memory, to use it to set goals and to establish the writing plan to guide the production of a text that will meet these goals);
  - translating (→ function: to take material from memory under guidance of the writing plan and to transform it into acceptable written English sentences);
  -reviewing (→ function: to improve the quality of the written text).

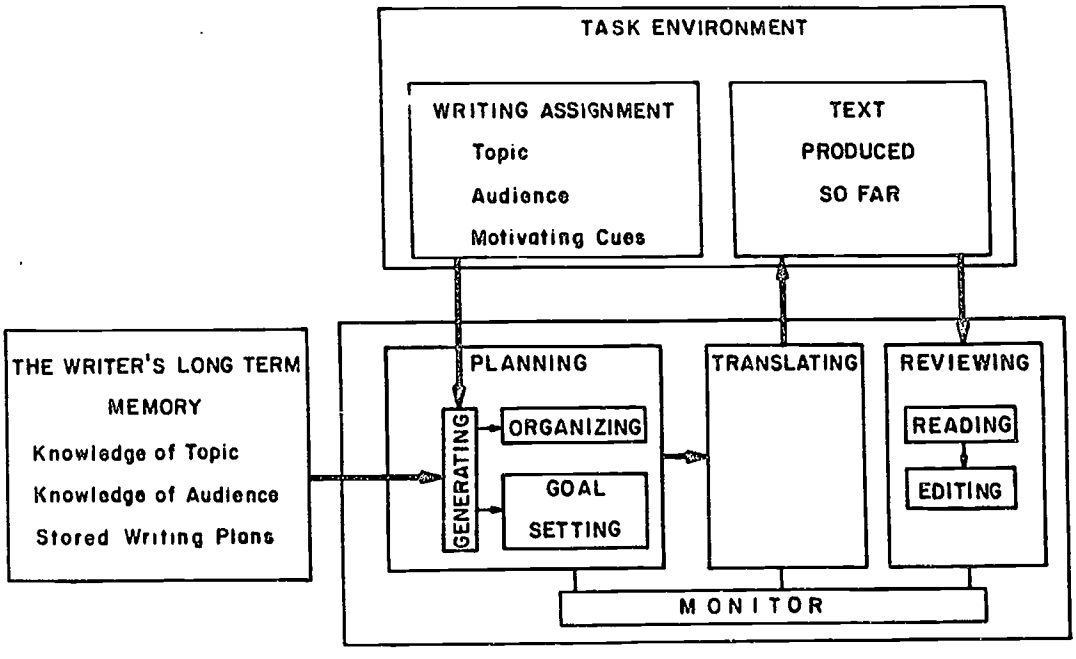

Figure 2: Structure of the writing model (Gregg & Steinberg, 1980):

2.4. Bipolar dimension tasks

An altogether different approach to the investigation of personal meanings is to ask pupils to rate a concept in terms of its position on some sort of continuum (based on the essence of the Osgoods technique, 1957). A stimulus word (say 'bacteria') may be seen as in a certain position on scales of bad-to-good, weak-to-powerful, passive-to-active. The results can be displayed in a two-dimensional or three-dimensional graph. The technique is of course concerned exclusively with personal and private meanings, not public definitions, and with these particular scales the technique may reveal the emotional connotations of the stimulus word rather than its logical connections. Words of very different denotative meaning can appear in similar positions in the 'semantic space'.

Whereas Osgood's test offers ready-made bipolar scales or 'dimensions' on which to rate a given stimulus word, one can also try to discern what dimensions are spontaneously being used by the learner, using Kelly's 'repertory grid' technique (described by Fransella and Bannister, 1977). A child may be given three objects, or asked to select three at random from a large number that are offered. He is then asked to consider any two of them which resemble each other in some way and are different from the third, and to say how they are different. Repetition of this procedure creates a list of bipolar dimensions which form the criteria which the child is consciously or unconsciously using in making sense of the information around him. In a sense we are here identifying the kind of 'mental spectacles' with which he views the world. Although Kelly's technique was designed to elicit continuously variable 'constructs' (i.e. bipolar continua) rather than classification concepts, in practice the respondent may make use of such concepts in doing the task. For example, a child who selects from some optical instruments a periscope, binoculars and a camera, and separates the former 'because it works on reflection only, while the other two use refraction', clearly has the concepts of reflection and refraction and can use them as mental 'tools'.

2.5. "Think aloud" methods

In recent years some researchers (e.g., Ericsson & Simon, Ginsburg, Black) have defended protocol analyses as a data base for exploring tasks (e.g., prose comprehension, problem solving, mathematical reasoning, writing) and mechanisms involving different knowledge domains.
Graesser (1981) contrasted complex verbal protocols with simple response measures as methods for investigating comprehension mechanisms.
Complex verbal protocols include "think aloud" protocols, Q/A protocols, question asking protocols, recall protocols, and other verbal protocols. Complex protocols are qualitative and supply rich patterns of information.
Simple response measures include reading times, priming latencies, lexical decision times, the duration of eye fixations, ratings of stimulus items, and other measures which normally have a quantitative scale.

In a verbal, or "think aloud" protocol, subjects are asked to say aloud everything they think and everything that occurs to them while performing the task, no matter how trivial it may seem. These think aloud data are reported in a protocol which provides the raw data for protocol-analysis.
Thinking aloud is often used in research into problem solving. Subjects are asked then to solve a problem or the primary task and to talk aloud meanwhile (the secondary task). An intervention is only made when the subject fails to perform one of the tasks.
A great advantage of this method is the immediate availability of qualitative data. Disadvantages are the complexity and the possibility for subjective interpretations of the data.

Thinking aloud in the model of Ericsson en Simon (1980), is a process during which all elements of STM (i.e. information that is 'in focus') are translated into natural language (spoken by the subject). Subjects mostly do not verbalize all information in the STM. Therefore, the protocol will often contain only a part of the elements.
From the Ericsson and Simon model, factors can be derived that influence 'thinking-aloud':

a. the ability to verbalize elements of STM;
b. the nature of the primary task;
c. the verbal capacities of the subjects;

d. a person's capacities related to the primary task.

The talking aloud procedure (Ginsburg, 1986) permits investigation of the complex activities that constitute problem solving and the exploration of the internal symbolic mechanisms that underlie it. Since the investigator plays a limited role in the protocol collection, the data can be viewed as relatively unbiased accounts of the individual subject's problem-solving performance and may shed light on individual differences in cognitive processes.

Consider a condensed version of a talking aloud protocol involving cryptarithmetic, adapted from Newell & Simon (1972, p.329).

The subject is presented with the problem DONALD + GERALD = ROBERT, and, given that D is 5, is asked to determine the numerical values of each letter.
I: I will give you that D is 5 in this problem. Please talk.
S: Well D...giving D=5 automatically makes T a zero. Could you make T a zero?
I: T is a zero.
S: Because 5 plus 5 is equal to 10. And that's simple form the problem. And looking at the leftmost column, you can see that R is either 1 or 2 greater than G, but that doesn't seem to help very much at this point. In the second column having the two L's equal, and also the two A's equal in the third column, doesn't seem to help much at this point either.....

The aims of investigators, who employ the talking aloud method, are to elicit and describe the integrated activities constituting complex problem solving in intelligent adults and to identify the cognitive processes and internal symbolic mechanisms underlying adult problem solving. It is argued that both of these aims are best achieved by obtaining data from a situation in which the subject deals with a challenging problem and in which there is a minimum of investigator intervention.

Different types of TOL (Thinking-Out-Loud) tasks (Kieras and Just, 1984) for collecting data can be distinguished:

* Sentence-by-sentence talking: the subject is asked to talk after each sentence in the text. The talking continues until the text is completed;
* Selective talking: subjects have to talk at only particular points in the text;
* After the fact talking: subjects have to talk about their cognitive experiences after the fact (→ risky, because memory is too fallible to allow for accurate reporting of earlier mental states).

One's specific theoretical and empirical goals will dictate which variant of the TOL task will be most useful in collecting the TOL data.

When thinking about TOL data there are several points about their use to keep in mind (Ericsson and Simon, 1980): in general, limits on what is available to be reported upon, what can be remembered, and on the human ability to offer explanations or justifications for one's own behaviour should be respected. Furthermore, TOL data provide a sample of what's on the subject's mind during the task.

A particular elaboration of the TOL method is the teach-back procedure. Following a sequence of classroom or textbook learning of some hours, the student is asked to teach the same material to another person with no prior knowledge (Snow, 1990). The session is recorded and then segmented into chunks using Chi's (1978) interresponse latency rule. These chunks are analyzed to yield measures of the number of units per chunk, correctness and completeness, degree of verbatim recall versus degree of elaboration, personalization, reorganisation and the amount of common or idiosyncratic misconceptions. Research by Gray (in Snow, 1990) showed that the results of this teach-back method correlated strongly with achievement tests administered before and after instruction. Moreover, the method provides the possibility to identify qualitatively different forms of knowledge structuring.

Analysis of TOL protocols can be done on the basis of the method proposed by Breuker (1982), called "analysis-by-synthesis". This method consists of a continued repairing and specifying of a theory. The protocols need to be interpreted. A first step in Breukers' method is the design of a interpretation-theory: a description how to interpret information in a protocol. For this purpose, taskanalysis and a sample of protocols can be used.
A first important decision is the choice of categories to distinguish and the relations between the categories. Further, this theory must be specified in a coding system for statements in the protocol. These codes are the operationalisations of the more abstract categories.
In a first phase of the analysis, a try out of these codes on a selection of protocols will be necessary. This can result in some changes in the coding system or the chosen categories. The complete theory will be developed by means of certain amount of these 'cycles', until the analyzing system fits to the format of protocols. Then, definite coding of all protocols can take place.
These will provide a basis for evaluation of the theory related to the individual differences between subjects and the generalization towards new protocols.
Ericsson and Simon (1984) also suggest for the analysis of protocols to split in units and to code them in order to avoid influence of the context and the preceding or proceeding processes.

3. Discussion: Applicability of the Knowledge Base Structure Methods for Research and Educational Practice

As advocated earlier, a method for investigating the cognitive structure of students could provide useful information for our research into the prior knowledge base of students. Especially the accessibility and relevance of the prior knowledge at a certain moment can be mapped. The purpose of this article is to seek for a priority in different methods related to this goal.

In our point of view there are several advantages and disadvantages that should be taken into account when considering these methods in investigating prior knowledge of students.
First, in a research context, a method providing cognitive structures gives information on the availability and relevance, the accessibility of prior knowledge and the information processing (Shavelson, 1985; Martin, 1985). This information could be vital for seeking an explanation for the different effects of prior knowledge (Hirschman, 1982; Lampert, 1986).
Secondly, apart from providing unique information, these methods are applicable to almost any subject-matter.

On the other hand, these methods are only applicable for a small group of students and thus not in educational practice with large groups of students (Snow, 1990). This is mainly due to the large amount of work required for gathering and analyzing data.

Generally speaking, data from measures of cognitive structures have been analyzed in three ways (Martin, 1985). Qualitative analyses have depended on detailed, descriptive accounts of the various dimensions of cognitive structure. When such data are quantified, they are analyzed with commonly employed descriptive and inferential statistics or subjected to complex scaling methods that attempt to provide sophisticated statistical solutions to the description of dimensions or factors that define various cognitive structures. The choice of analytic methods employed depends, of course, on the exact purposes of individual researchers.

As measures of structure, Shavelson and his associates have applied several psychometric techniques that make use of coefficients of concept interrelatedness. Word association, graphic construction, and/or card-sorting tasks have been used to assess the similarity of key instructional concepts. Then, multidimensional scaling, hierarchical clustering, and graphic representation of these judgements are used to reflect students' cognitive structure of those concepts.

Multidimensional scaling uses proximal scaling techniques to place concepts in relation to each other on a matrix (Nagy, 1978). This method assumes that relationships between concepts are unidimensional rather than multifaceted or logical in nature. The method does, however, show the degree of relationship among the set of concepts.

Methods of analyzing course data using proximal and logical methods in conjunction could be expected to more accurately depict course content. One of these methods is propositional analysis, in which the principal propositions in a course are extracted from text or lecture material and then subjected to tests from subject matter experts and students to determine the underlying structure in a course (Donald and Nagy, 1985).

For the purpose of research into the structure of an individual's knowledge base, it is necessary that a method is used which holds possibilities for individual associations or thoughts and free response (Hirschman & Wallendorf, 1982; Ericsson & Simon, 1980). Checking the different methods discussed above, only the free recall method and think aloud method could be useful. A more time consuming method could be to use the concepts resulting from a free recall session as a starting point for a graph construction test or a bipolar dimension task. Further, we have to take into account that our goal is to develop instruments that are applicable in educational practice and useful for a large student population, as are the different domain-specific knowledge state tests and knowledge profiles (Dochy, 1992). Therefore, only the free recall method seems to be appropriate to our conditions and may add information to our analysis of students' knowledge profiles before they follow a particular study traject.

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