EXTRACTING, REPRESENTING

AND ANALYZING MENTAL MODELS *

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ABSTRACT

When making decisions or talking to others, people use mental models of the world to evaluate choices and frame discussions. This paper describes a methodology for representing mental models as maps, extracting these maps from texts, and analyzing and comparing the extracted maps. The methodology employs a set of computer-based tools to analyze written and spoken texts. These tools support textual comparison both in terms of what concepts are present and in terms of what structures of information are present. The methodology supports both qualitative and quantitative comparisons of the resulting representations. This approach is illustrated using data drawn from a larger study of students learning to write where it is possible to compare the students' mental models with that of instructor.

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INTRODUCTION

Mounting interest in the cognitive foundations of social behavior has led, in the methodological arena, to a growing interest in representing and analyzing the mental models of individuals. Researchers in an increasing number of social science and humanistic fields, among them organizational behavior (Eden, Jones and Sims, 1979), sociology (Carley, 1986a; Roberts, 1987), rhetoric and composition (Gere, 1987; Gere and Stevens, 1985; Langer and Applebee, 1986; Michaels, 1987), sociolinguistics (Edwards and Mercer, 1986; Stubbs, 1983), and political science (Axelrod, 1976; Bonham, Shapiro and Nozicka, 1976), have begun to examine more closely the relationships between social behavior and individual cognition. Interest in representing the mental models of individuals has thus moved far afield from much of the earlier, and in many cases continuing, work in artificial intelligence and cognitive science (Anderson, 1983; Newell, 1990; Rumelhart, 1986).

Despite this wide-spread interest, techniques for extracting mental models have lagged behind more theoretical concerns. As a result, current methods do not fully support efforts to address these concerns. However, recent advances in artificial intelligence, cognitive psychology, and network analysis have created the potential for a new methodology. These advances both provide a theoretical foundation for such a methodology and suggest a set of techniques that can be employed to extract, represent, and analyze mental models. In this paper, we present a methodology, based on work in these disciplines, that can be used to accomplish these goals.

Many theoretical issues underlie the development and use of textual analysis techniques to represent mental models. Those most salient to our approach are: 1) the relationship between mental models and language, 2) the relationship between words and meaning, and 3) the nature of social knowledge or shared meaning. Our purpose is not to engage in an extended discussion of the epistemological foundations of previous methodologies or our proposed methodology. We point these issues out in passing, simply to alert the reader to the fact that there are strong theoretical and philosophical considerations underlying the development and use of textual analysis techniques and that this paper takes a stance on these issues. This stance underlies the methodology described in this paper and is epitomized by the following claims: 1) mental models are internal representations; 2) language is the key to understanding mental models, that is, mental models can be represented linguistically and those representations can be based on linguistic accounts; 3) mental models can be represented as networks of concepts; 4) the meaning of a concept for an individual is embedded in its relations to other concepts in the individual's mental model; and 5) the social meaning of a concept is not defined in a universal sense but rather through the intersection of individuals' mental models.

The argument that individuals have mental models which serve as internal representations of the world or aspects of the world is not new, nor is it exclusive to cognitive psychology. Mental models are central to theories in which individuals represent the world and interact with it through symbols, such as in the work of Mead (Mead, 1962, 1964) and the symbolic interactionists (Blumer, 1969; Stryker, 1980), and in theories in which individuals even create the world using these symbols, such as in the work of the social constructivists (Knorr-Cetina, 1981; Latour and Woolgar, 1979). Recently, however, this conceptualization has received more systematic form through the work on schemas and frames (Fiske and Taylor, 1984; Goffman, 1963, 1974; Minsky, 1975; Schank and Abelson, 1977) and most recently through Johnson-Laird's (1983) work on mental models.

Similarly, the assumption that language is a key to -- and perhaps mediates the development of -- these mental models is also not new. Vygotsky and Luria, for example, argue that language mediates thought, thus affecting categorization and behavior to the extent that different social behaviors arise when language differs (Vygotsky, 1962, 1978; Luria, 1978, 1981). A similar emphasis on the mediating role of language is seen in the work of cognitive sociologists (Carley, 1984, 1986a; Cicourel, 1974), symbolic interactionists (Blumer, 1969; Cooley, 1902; Mead, 1962; Stryker, 1980), cultural theorists (Namenwirth and Weber, 1987), and organizational theorists (Feldman and March, 1981). This perspective is eloquently summarized by Stryker (1980) who argues that:

> Humans respond not to the native world, but to the world as categorized or classified; the physical, biological, and social environment in which they live is a symbolic environment. The symbols that attach to the environment have meaning, are cues to behavior, and organize behavior (p. 56).

Stryker's observations underscore the notion that we can use language as a window through which to view the mind of the individual. By studying language, we can build representations of the mental models that inform social action. Moreover, through analyzing the social use of language -- in both written and oral texts -- we can build representations of the models that inform and shape those texts.

To argue that language provides a window on the mind is not to argue that there is a one-to-one mapping between the verbal structure[1] of a text and the cognitive structure of an individual. Rather, the relationship is more complex, depending on both the modeling scheme or representation being used and the sampling procedure. Essentially, our argument rests on three assumptions. First, both the cognitive structure and the text can be modeled using symbols, i.e., concepts. Second, the text is a sample of what is known by the individual and hence of the contents of the individual's cognitive structure (Carley, 1988; Cicourel, 1974; Luria, 1981). And third, the symbolic or verbal structure extracted from the text is a sample of the full symbolic representation of the individual's cognitive structure (Carley, 1988; Fauconnier, 1985; Sowa, 1984). The completeness of this sample is presumably a function of a variety of factors including the method of extraction, the original mode of communication, the length of the text, and so forth. This last point, however, is both well beyond the scope of this paper and an issue that needs further research.

Our third assumption, that mental models can be represented as networks, has a more recent intellectual history than our first two assumptions. A variety of schemes have been proposed, all of which share, at some level, a basic network orientation to mental models: conceptual structures (Sowa, 1984), schemes (Anderson, 1973; Bobrow and Norman, 1976), schemata (Rumelhart, 1976; Tversky, 1980), structured frames (Charniak, 1972; Minsky, 1975), dynamic frames (Goffman, 1974), transition networks (Winston, 1977; Clark and Clark, 1977; Collins and Loftus, 1975; Wyer, 1979), semantic nets (Schank and Colby, 1973), scripts (Schank and Abelson, 1977), and decision networks (Axelrod, 1976; Eden, Jones and Sims, 1979). At a gross level of generality, all of these approaches characterize mental models as semantic structures. In these structures, verbal statements are represented as visual structures in which concepts and the relationships between those concepts are specified.

The methodology presented in this paper follows directly from these rather time-honored conceptions of mental models. However, it departs from many earlier attempts to build representations of these models in several important ways. Two of these are its relationship to a structural theory of meaning (Carley, 1988; Sowa, 1984) and its reliance upon a theory of knowledge acquisition (Carley, 1986b; Fauconnier, 1985). In addition, despite the long intellectual history underlying mental models, earlier attempts to represent mental models produced a confusing panoply of tools that often fail to generalize across projects, tend to suffer from lack of automation, are rarely theoretically grounded, and do not admit cross-model comparison. In contrast, the methodology we present in this paper is highly general, semi-automated, theoretically grounded, and facilitates cross-model comparison. The proposed methodology includes a standardized procedure for representing mental models in terms of model primitives (concepts and statements)[2] which, when coupled with a delimited vocabulary, makes cross-model comparison feasible at both qualitative and quantitative levels. Further, the proposed methodology employs sparse-matrix and information-processing techniques to enable rapid encoding and analysis. The methodology we present in this paper employs a four-step process for extracting mental models from texts where the researcher: 1) identifies concepts; 2) defines the types of relationships that can exist between those concepts; 3) using a computer-assisted approach, codes specific texts using these concepts and relationships; and 4) takes the resultant coded mental models and displays them graphically or analyzes them statistically.In subsequent sections of this paper, we present this methodology and provide an extended demonstration of it using data drawn from a previous study of students learning to write done by Palmquist (1990). Selected raw and coded data from this study is provided in Appendix 1.[3] At times, we will also draw illustrative examples from a study of students choosing a tutor (Carley, 1984).

PREVIOUS WORK IN REPRESENTING MENTAL MODELS

Johnson-Laird (1983) observes that "human beings understand the world by constructing working models of it in their minds" (p. 10). These models are constructed, he argues, when we make inferences that can be either explicit -- requiring "a conscious and cold-blooded effort" (p. 127) -- or implicit -- "rapid, effortless, and outside conscious awareness" (p. 127). This suggests some important considerations. First, mental models as "working models" are dynamic structures. This observation underscores the importance of representing the dynamic qualities of mental models. We might, for instance, attempt to represent not only the type of relationships in a given model but also the strength and direction of those relationships and, possibly, the manner in which they change over time. Second, the distinction between explicit and implicit inferences suggests that we must consider not only the structure that is built from our inferences but also the conditions under which inferences are made. By further suggesting that some of the inferences we make are "outside conscious awareness" Johnson-Laird is reminding us of the importance of considering situational and sociocultural context in our representations of those models.

Previous efforts to represent mental models have not provided representations that meet the criteria suggested by Johnson-Laird's observations. Typically, researchers have tended to represent mental models in one of three ways: content analysis (Namenwirth and Weber, 1986; Stone, 1968a, 1968b), procedural mapping (e.g., semantic-planning nets (Leinhardt, in press; VanLehn and Brown, 1980) and task analysis (Ericsson and Simon, 1984; Newell and Simon, 1972)), and cognitive mapping (Moshe et al., 1986; Reitman and Rueter, 1980; Shavelson, 1972). Content analysis examines the content of written texts and generalizes from the frequency with which particular words are used in those texts. Texts can range from student generated papers (Iwanska, 1989) to presidential addresses (Sullivan, 1973). Procedural mapping attempts to characterize the implicit and explicit procedures used by a speaker or author to perform a given task. One type of procedural mapping, semantic-planning nets, characterizes the range of decisions that individuals might make as they engage in a given activity. Activities that are typically studied through the use of procedural mapping include such problem-solving tasks as mathematics (VanLehn and Brown, 1980) and chess (Simon, 1979). Cognitive mapping is an attempt to represent the "cognitive structures" in memory. Shavelson (1972) defines cognitive structure as "a hypothetical construct referring to the organization (relationships) of concepts in memory" (pp. 226-227). Cognitive mapping focuses on both concepts that are in a text and the relationships between those concepts.

Each approach has applications for exploring the nature of shared knowledge in social groups. Of the three, content analysis has been the most widely used by social scientists (Berelson, 1952; Fan, 1988; Namenwirth and Weber, 1987; North, 1963; Ogilvie, Stone and Kelly, 1982; Stone, 1968a). The strengths of content analysis are that it can be highly automated and that it is relatively easy to generalize across individuals and hence groups. Despite its wide use, however, its potential role in exploring the nature of shared knowledge in social groups is limited. One of the most severe drawbacks of content analysis is its inability to take into account the context in which the "content" appears. Because content analysis focuses primarily on the frequency with which words or phrases occur in texts and not on the relationships between those words, it tells us less about the structure of a given text than it does about its content. As such, it does not suggest the structural or semantic relationships between words and phrases in a text. We suggest that content analysis tells us about the "content" of a text, but not the "meaning" of that text. That is, content analysis can tell us about the fundamental building blocks of a text, but not the structure in which those blocks are arranged.

In contrast, procedural mapping can tell us a great deal about the structure of a given task and the repertoire of procedures that an individual can draw upon as he or she engages in it. As a result, it allows us to gain a richer understanding of the processes that individuals engage in than does content analysis. However, it focuses on the task domain itself rather than upon individuals or groups. As a result, while procedural mapping can provide the investigator with an understanding of the sequence of task-related decisions made by an individual, it tells us little about the general knowledge that individual might have on a given topic. In this sense, procedural mapping also fails to reveal the "meaning" of a text. That is, by focusing on the structure of the task itself, procedural mapping tells what approach the individual takes, but not why the individual took it.

Cognitive mapping is perhaps the most useful means of exploring the nature of shared knowledge in social groups. It can be used on relatively large numbers of individuals and its results can be compared to each other, to the cognitive maps of experts, or to idealized representations of the content structure of a given domain. Cognitive mapping is often employed in expert/novice comparisons (Chiesi, Spilich and Voss, 1979; Means and Voss, 1985), studies of classroom learning (Gussarsky and Gorodetsky, 1988; Moshe et al., 1986), and studies of decision making (Axelrod, 1976; Carley, 1986a). Investigators attempt to determine the extent to which cognitive structures change over time and differ across individuals. In the classroom, for instance, cognitive maps of students are constructed at various points during an academic term and contrasted with the structure of knowledge (typically termed content structure) of the instructional materials being used in the classroom (Moshe et al., 1986). In expert/novice studies, cognitive maps are compared across pre-defined groups of experts and novices (see, e.g., Chiesi, Spilich and Voss, 1979). Like content analysis, many of the procedures involved in cognitive mapping can be automated. Moreover, it subsumes content analysis in that it can provide information concerning the frequency with which words and phrases occur in a given text. Unlike content analysis, however, it can be used to explore the relationships between those words and phrases. As such, it allows for a more thorough exploration of the meaning of a given text.

Our interest in the structural and semantic relationships that are present in texts and our desire to conduct cross-group comparisons of individuals, along with the desire to automate as much of the data collection and analysis procedures as possible, lead us to favor cognitive mapping as a means of representing mental models. Cognitive mapping is not a well-defined technique, however, and numerous methodological approaches fall under its rubric. Data-collection techniques include free- and cued-recall (Chiesi, Spilich and Voss, 1979; Reitman and Rueter, 1980), free association (Moshe et al., 1986), open-ended interviewing (Finch et al., 1987), work-sheets (Gussarsky and Gorodetsky, 1988), and pattern notes (Jonassen, 1987). Data-analysis techniques range from measuring the length of pauses during recall (Reitman and Rueter, 1980) to assessing the distance between key terms in diagrams or notes (Jonassen, 1987) to assessing relationships through qualitative interpretation of interview transcripts (Means and Voss, 1985). The results of cognitive mapping can be equally diverse. Cognitive maps vary from representations of hierarchical dependencies (Means and Voss, 1985) to attempts to define distances between concepts in terms of a multidimensional space (Jonassen, 1987) to clusters of concepts defined by pauses between utterances (McKeithen et al., 1981; Reitman and Rueter, 1980).

The diverse techniques and analyses employed in cognitive mapping suggest the breadth of interest in this methodology. Still, each of these techniques has limitations that space-limitations prevent us from detailing here. Our over-riding concerns involve: 1) lack of automation, 2) lack of procedures that admit cross-individual comparison in practice (though not in theory), and 3) questions of representation. In the following sections, we present an alternative approach to representing mental models which attempts to address these concerns. Because the approach relies heavily on the use of computer-based tools, it is relatively simple and does not require extensive pre-processing of the texts. In addition, the approach also allows the researcher to construct and compare representations of mental models in a rigorous fashion without losing the richness of detail present in more qualitative approaches. Finally, because the nature and structure of relationships is specified in the mental models being represented, the approach emphasizes meaning and allows the researcher to determine, through an examination of the ways in which people inter- relate concepts, whether people mean the same thing by the words that they use.

PROCESS AND METHODOLOGY FOR EXTRACTING MENTAL MODELS

Texts can be analyzed from either a confirmatory or an exploratory perspective. The confirmatory perspective can be typified by the question, "Does the text contain what I expect it to contain?" In contrast, the exploratory perspective can be typified by the question, "What does the text contain?" The process for representing and analyzing mental models that we introduce in this paper employs a set of tools that can be used regardless of the perspective taken. However, depending on the perspective taken by the researcher, the extraction process, i.e., the approach to data collection and coding, will differ in important ways. As we describe the process and associated tools, differences due to the researcher's perspective will be highlighted.

Representation Scheme

There are four basic objects in the representation scheme we employ: 1) concepts, 2) relationships, 3) statements, and 4) maps. Essentially, we represent mental models as a network of concepts and the relationships between them. This basic representation scheme has been described in detail elsewhere (Carley, 1988), as have its cognitive underpinnings and relationship to alternate representation schemes in artificial intelligence (Carley, 1986a, 1986b, 1988). Thus, in this paper we limit ourselves to a brief overview of the scheme. Further, we take an operational focus by emphasizing only those aspects of the scheme that the researcher needs to know to make use of the process described here.

Concepts

A concept can be a single word such as "friend" or "writing," or a phrase such as "works well with others." In this sense, a concept is an ideational kernel -- a single idea totally bereft of meaning except as it is connected to other concepts (Carley, 1986b). Concepts are nothing more than symbols whose meaning is dependent on their use, i.e., their relationship to other symbols (Carley, 1986a, 1986b, 1988; Gollob, 1968; Heise, 1969, 1970; Minsky, 1975). A set of concepts is referred to as a vocabulary or lexicon. There is presumed to be a countable and generally finite number of concepts at any one time in any one sociocultural environment. Concepts can be classified or typed. There is, a priori, no one right classification scheme.

Relationships

A relationship is the tie that links two concepts together. Examples of such relationships include "loves," "does," "if then," and "is less likely than." The relationships can have directionality, strength, sign, and meaning (Carley, 1984).

Directionality: The relationship between two concepts can be uni-directional -- e.g., "goes for advice to" -- or bi-directional -- e.g., "equals."

Strength: The relationship between two concepts can vary in strength -- e.g., "went for advice once" or "often goes for advice."

Sign: The relationship between two concepts can vary in sign, thus indicating a positive relationship -- e.g., "increases" or "loves" -- or a negative relationship -- e.g., "decreases" or "hates."

Meaning: The relationship between two concepts can vary in meaning -- e.g., "is friends with" or "works with."

Statements

A statement is two concepts and the relationship between them. Some examples of statements are "papers have abstracts," "a father is a member of a family," and "if it rains then the sun will not shine."

Maps

A map is a network formed from statements.[4] By sharing concepts, statements can form networks. For instance, the two statements "Tanya works with Cassi" and "Corwin works with Cassi" share the concept "Cassi." The resultant network, or map, is a representation of a mental model.[5]

Four-Step Process

We now propose a four-step process for extracting mental models from texts. First, the researcher identifies the set of concepts that will be used in coding the texts. Second, the researcher defines the types of relationships that can exist between these concepts. Third, the researcher uses a computer-assisted approach to code the information in a text as a set of statements using these concepts and relationships. The resultant map serves as a representation of the mental model. The choices made in the first two steps place restrictions on the resultant maps. Finally, the researcher can display the resultant map graphically and analyze it statistically. Thus, maps drawn from different texts can be compared.

In detailing this process we will provide information on a variety of tools, two of which are automated (***STARTUP*** and ***CODEMAP***).[6] ***STARTUP*** asks the researcher a series of questions about the choices that the researcher made in the first two steps of this process. ***STARTUP*** takes these choices and records them in a file. This file acts as a template for coding texts. ***CODEMAP*** uses the template file produced by ***STARTUP*** to tailor the questions it asks the research when extracting maps from texts. These questions ask the researcher to identify concepts in the text and the relationships between those concepts. In Figure 1 we portray the relationship between these tools, the texts, and the researcher.

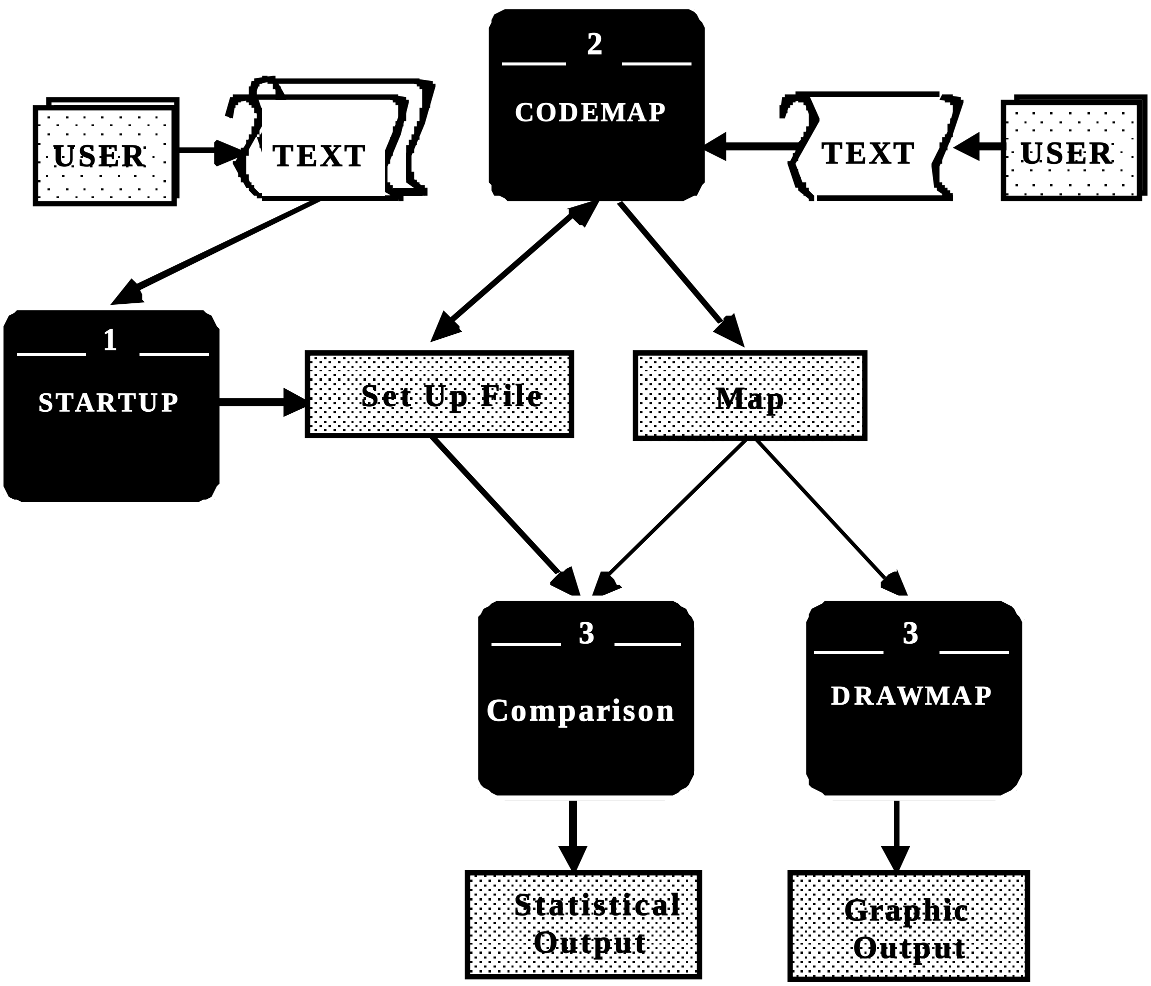


Figure 1. Inter-relationship Between Software Programs

Step 1: Identifying Concepts

To identify concepts, the researcher must first decide whether to take a confirmatory approach or an exploratory approach. The critical difference is that when the confirmatory approach is taken the words are defined independent of and prior to coding any texts whereas when the exploratory approach is taken the words are drawn from the texts themselves.

Traditional content analysts, such as Fan (1988), often create dictionaries of concepts that they wish to search for prior to analyzing texts. Similarly, researchers who employ cognitive mapping often pre-define their concepts, particularly when the domain is well-defined. For example, Shavelson's (1972) study of students' learning focused on concepts that were closely tied to physics, and Gussarsky and Gorodetsky (1988) confined their representations to 18 concepts associated with chemical equilibrium. The point to remember is that when a confirmatory approach is taken the number of concepts is known a priori.

Not all studies, however, deal with such well-defined conceptual realms. In classroom studies, for instance, the extent to which an academic task is well-defined can play a major role in the decision to adopt a confirmatory or exploratory approach to identifying concepts. Research writing, for example, is a relatively ill-defined academic task. As a result, a confirmatory approach may fail to capture important concepts that would appear in a more exploratory analysis. In Palmquist's (1990) study of two writing classrooms, he might have chosen to pre-identify important concepts using what Shavelson (1972) terms the "content structure" of the textbooks used in each class, thus taking a confirmatory approach. However, he began with an exploratory approach because it was impossible to anticipate 1) the teacher's and students' decisions concerning which of those concepts would become important in the context of each classroom and 2) the prior knowledge and writing experiences that students brought to the class. By adopting an exploratory approach, Palmquist was able to identify concepts that became widely used in each classroom over the course of the study.

When an exploratory approach is taken, the list of concepts is drawn from the texts to be examined in a dynamic fashion. That is, as the researcher goes through the texts, he or she continually identifies new concepts. These concepts may be the exact words used by the text's author or they may be generalizations of those words. Using generalizations typically increases the level of comparability across the resultant maps.

One might worry when taking the exploratory approach that the list of words will simply keep growing. Our experience indicates that this is not the case. That is, for any one task or decision, people seem to have a limited vocabulary. For example, Carley found that 217 concepts were sufficient to describe the mental models drawn from interviews with 45 undergraduates, involved in choosing a new tutor. Palmquist found that 212 (conventional class) and 244 (nonconventional class) concepts, respectively, were sufficient to describe the research writing mental models of the 29 undergraduate writing students enrolled in the two writing classes.

Another important consideration in determining which approach to adopt is the design of an instrument that is used to elicit written or spoken texts. While Palmquist and Carley found that the open-ended nature of their interview questions and, in Palmquist's case, his writing prompts allowed the use of an exploratory approach, studies which use more structured prompts (e.g., a workbook in which a set of key concepts is arrayed in different ways on successive pages) and in particular studies employing pre-test/post-test designs may find the confirmatory approach more appropriate.

Extracting Concepts

Regardless of the perspective taken, a number of techniques can be used to identify concepts. These approaches range from relatively non-automated to highly automated approaches. One non-automated approach typically used when taking an exploratory approach involves a close analysis of a small but representative sample of texts. In this procedure, the investigator might read each of these texts and, using a highlighter, mark those words related to the issue under consideration. Next the researcher might generalize these words into a set of concepts. This procedure provides the investigator with a base vocabulary that can be expanded as additional texts are read. In studies in which coding assistants are used, it is often useful to create a file giving examples of exact words that correspond to each of the generalized concepts. A more automated approach might involve the use of a text-analysis program to identify all words used in each of the texts collected in the study. Palmquist employed utility programs found on the UNIX operating system to identify the frequency with which words were used within and across all texts analyzed in his study. Having identified frequently used words and phrases, he subsequently used a program to search for and mark the occurrence of each concept in the text. Figure 2 contains an excerpt from an interview with one of Palmquist's students at the beginning of the term in which the frequent substantive concepts are underlined. Other portions of this interview are in Appendix 1. In this excerpt the number in brackets on the left identifies the line of the students' response. In addition, we have emboldened those phrases or words which, although not frequent, correspond to concepts in the research-writing vocabulary being developed. All identified concepts are listed on the lower left. The generalized concept corresponding to each of the identified concepts is listed on the lower right.

In addition to identifying concepts, a researcher may wish to categorize concepts. If a confirmatory perspective is taken, the researcher will have not only a predefined set of concepts, but also a predefined set of concept categories. If an exploratory perspective is taken, the researcher may develop concept categories after examining some or all of the texts. For many applications there is no need to classify concepts. In such a case, the researcher would simply say that there is only one category of concepts.

TEXT

Interviewer: Step by step... What's the first thing that you do?

[1] Student: Get a topic.

Interviewer: What do you mean by a "topic"?

[2] Student: What you are going to write on.

Interviewer: Okay, then what would you do after that?

[3] Student: Go to the library and find out something about **it**

Interviewer: How would you find out...

[4] Student: **Magazines**, books, encyclopedias...

Interviewer: Anything else.

[5] Student: Nothing offhand,

[6] I mean there's things,

[7] if you had resources you would know something offhand.

Interviewer: Okay, you have the books and magazines.
What would you do next?

[8] Student: **Read them** (laughs).

Interviewer: Okay, after you have read them?

[9] Student: **Decide specifically what** you are going to write down,

[10] **which side of** the issue or something,

[11] trying to get down ideas,

[12] make a general outline,

[13] just a few ideas of what you are going to write about.

Interviewer: So you would move from a topic to an issue that you would write about? What would the issue be?

[14] Student: Like f**or or against** whatever the topic was.

EXTRACTED CONCEPTS	**GENERALIZED CONCEPTS**
book	books
decide specifically what	topic
encyclopedia	encyclopedia
facts	fact
find	find
for or against	sides
ideas	idea
issue	issue
it	topic
library	library
magazine	books
outline	outline
read them	research
research writing	writing
resources	books

topic	topic
which side of	sides
write	writing

Figure 2. Annotated Text Segment

Step 2: Defining Relationships

To define relationships, the researcher must specify how strength, sign, directionality, and meaning will be used. There are many ways of using these relationship characteristics. We will limit the following discussion to ways of using these characteristics that can be handled by the associated computer tools ***STARTUP*** and ***CODEMAP***.

Strength: Strength is a number which can be be used in a variety of ways to indicate the presence, degree, or valence of the relationship between two concepts. Strength can be used to denote existence, i.e., whether the statement is in the text and hence in the individual's mental model. In this case, within ***STARTUP*** , the researcher would set strength to denote existence -- within the program a "0" indicates no relationship and a "1" indicates the presence of a relationship. This approach was taken by Palmquist (1990), who was solely interested in whether statements were or were not present in the representations of each student's mental model. This approach permits the maximum level of cross-model comparison. Strength can also be thought of as denoting existence plus valence. In this case, strength would indicate that there is a positive or a negative relation between concepts. In addition, strength can be thought of as the certainty of the coder's judgment that the relationship exists between two concepts or the emphasis in the text given to this relationship by the speaker or writer. In this case, within ***STARTUP***, the researcher would set strength to a range and then define the minimum and maximum value. Let us consider two examples: certainty and emphasis plus valence. In the first example, strength can be thought of as the certainty or belief that the individual has for that statement (as is done in many diagnostic expert systems, such as MYCIN (Buchanan and Shortliffe, 1985)). In this case, within ***STARTUP***, the researcher would set a strength range from 0 to 100. In the second example, strength can be thought of as the level of emphasis. This approach was taken by Carley (1984), who used strength to differentiate between whether a statement was implied or occurred explicitly in the text. In this case, within ***STARTUP***, the researcher would set a strength range from, for instance, -3 to 3, keeping in mind that a 1 refers to an implied relationship, a 2 to a stated relationship, a 3 to a repeated relationship, a -1 to an implied negative relationship, a -2 to a stated negative relationship, and a -3 to a repeated negative relationship. These two examples simply serve to illustrate how the researcher might use a limited range of strengths, and not to delimit all possible ways in which strength can be used. Finally, strength can be thought of as the level of usage. In this case, within ***STARTUP***, `the researcher would set strength to denote the number of occurrences of a statement.

Sign: The sign of a relationship can be either positive or negative. Setting sign depends on how concepts are defined. For example, if all concepts are defined as positive terms, such as "fits in" or "goes to the library," then a negative relationship is needed if one wishes to distinguish "John does not go to the library" from "John goes to the library." This was the approach taken in Carley (1984). In contrast, if concepts are defined separately as negative and positive, then all relationships may be positive. In this case, there would be two concepts -- "goes to the library" and "does not go to the library" and a single positive relationship. The relative merits of the two approaches is a topic for future research in this area. We simply note here that the researcher needs at this stage to make a commitment to one approach or the other for dealing with negative relationships. Within ***STARTUP*** the researcher denotes sign by setting the strength range.

Direction: Directionality determines for two concepts -- such as "Tanya" and "Cassi" -- whether "Tanya" has the relationship to "Cassi" or "Cassi" has the relationship to "Tanya." There are three options: 1) all relationships are uni-directional, 2) all relationships are bi-directional, and 3) some relationships are uni-directional and some are bi-directional. The research objective will dictate which option is appropriate. For example, Carley (1984a, 1986a) used both uni- and bi-directional relationships because statements could denote either an equivalence relationship (bi-directional), such as the case "some one who lives on the hall is a third easter," or a propositional relationship, such as the case "if someone is a gnerd then they won't fit into the hall." In contrast, Palmquist (1990) used all bi-directional relationships as the focus of the research was on simply whether the individual somehow related the words.

Meaning: Meaning determines the type of relationship. For example, Axelrod (1976), distinguished two relational types, causal and definitional relationships. For many analyses, it is not necessary to consider the type of the relationship. Neither Carley (1984) nor Palmquist (1990) distinguished types of relationships when comparing maps. However, automated coding procedures can be facilitated by distinguishing types of relationships (Carley, 1988). When types are defined it is possible for there to be more than one relationship between a pair of concepts such as "Tanya is friends with Cassi" and "Tanya works with Cassi." Each of these will occur in the resultant map as a different statement. In most applications, the researcher will want to limit the number of possible statements by limiting the number of concepts and types of relationships.

If the researcher takes a confirmatory perspective, the strength, sign, directionality, and meaning of relationships are pre-defined based on theoretical considerations. In contrast, if the researcher takes an exploratory perspective, the characterization of strength, sign, directionality, and meaning of the relationships is derived from the data, usually by examining a sample of texts. It is possible to take a confirmatory perspective for defining concepts and an exploratory perspective for defining relationships or vice-versa.

As a general procedural comment we find that, even when taking an exploratory perspective, it facilitates coding to take a limited number of the texts and locate exemplar relationships, predefine how strength, directionality, and sign will be used, and predefine what meanings for relationships will be used. Such a procedure makes it possible to use minimally trained assistants to code the texts. Further, from a purely technical point of view, the automated procedure for coding maps, ***CODEMAP*** , dynamically adjusts to different characterizations of relationships so as to ease the coding task for the researcher. For example, if strength is used to simply indicate presence or not and there is only one type of meaning for relationships then ***CODEMAP*** does not ask for the relationships meaning and automatically codes a new statement as having a strength of 1. Since it is difficult to change information concerning relationships midway through coding the texts, we suggest that even when taking an exploratory approach the researcher sets these types first.

Using ***STARTUP***

Once the concept categories and the relationships are defined, ***STARTUP*** can be used to encode this information. As noted previously, Palmquist (1990) took an exploratory approach to concept identification, used only one category of concept, used strength to denote existence, used only bi-directional relationships, and did not define any special type of relationships. Following is an interchange between the program ***STARTUP*** and the researcher that illustrates the entry of this set of decisions for the nonconventional classroom. In this example, the software's response is in bold, the researcher's response is in plain text, and annotated explanations are in italics. The result of this process is a template file that will control the future operation of other software. Should the researcher change his or her mind about the number of concept categories, or the strength, direction, or type of relationships a new template will need to be created with ***STARTUP***.[7]

WELCOME TO STARTUP V4

Copyright (c) 1990 Carley

This program is used to enter the set-up information used by the following MECA programs -- CLIST, CMATRIX, CODEMAP, COMPRA, CUBE, SCOMPRA, SKI, SMATRIX

This program is entirely interactive. A series of questions will be asked. After answering the question simply type a carriage return.

The output file is an asci file.

What would you like to call the file containing the set-up information?

??? mysetup.dat _*this can be any name that you would like for the template file*

You can classify concepts into a maximum of 9 categories

How many concept categories are there?

??? 1 _ *because Palmquist did not distinguish categories*

Name of concept category 1? book2 _ *must be one word*

Are statements:

1) Some uni- and some bi-directional

2) All uni-directional

3) All bi-directional

??? 3 _ *because Palmquist did not want to distinguish directionality*

Are you using strength:

1) To denote existence

2) To denote existence and sign

3) A range of strengths

4) Number of occurrences of this fact

??? 1 _ *because Palmquist only wanted to denote that there was a relationship*

You can classify relationships (links) into a maximum of 9 types

How many types of links are there?

??? 0 _ *because Palmquist did not distinguish any special types of relationships*

How many concepts in category book2 do you currently have? 0 _ *because Palmquist took an exploratory approach to concept definition*

THANK YOU FOR USING STARTUP

Your data is being stored in the file mysetup.dat.

It can be edited with a standard text editor.

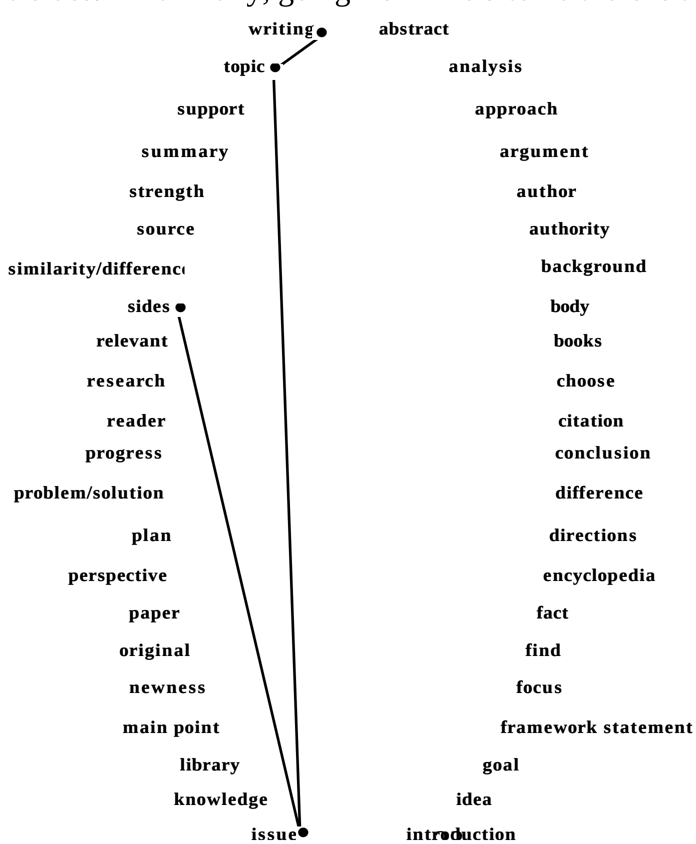
Step 3: Extracting Statements

Statements can be extracted from two sources. A researcher may work with pre-existing texts, such as interview transcripts, books, or short written texts, or directly with the subjects. In all cases, the researcher codes the map one statement at a time. The researcher locates two concepts, and then specifies the relationship between them. This information is entered into ***CODEMAP***. The researcher repeats this process, one pair of concepts at a time, until the entire model is coded. When a confirmatory approach is taken, the researcher assumes that he or she knows all possible statements. In a sense, the researcher adopts the position of a subject-matter expert. In coding the data, the researcher attempts to determine, for each pair of concepts, whether a pre-established relationship occurs between them. When adopting an exploratory approach, the researcher assumes a position more akin to a literary scholar, interpreting the data in an attempt to determine the nature of the relationships that the speaker or writer makes between concepts.

Previously extracted texts: In our discussion, we have referred frequently to written and spoken texts. In our own studies, such texts have typically been composed in response to writing prompts (e.g., "What is the purpose of research writing? What steps would you follow in writing a research paper?") and open-ended interview questions (e.g., "What do you usually do when you write a research paper?" or "What qualities should a tutor have?"). Other researchers, however, have used other approaches to elicit texts. Jonassen (1987), for instance, used a technique called pattern notes to elicit responses from the students in his study. Gussarsky and Gorodetsky (1988) used workbooks in which single concepts were printed on each page. Reitman and Rueter (1979) employed free-recall techniques, while Moshe, et al. (1986) used cued-recall. These "texts" have, in turn, been interpreted in what are often extremely different ways.

Jonassen, employing multidimensional scaling, determined the relative distance between concepts in each participant's pattern notes. In contrast, Reitman and Rueter, along with Moshe et al., measured the length of the pauses between utterances and characterized the relationships between concepts using hierarchical clusters.

"Live" subjects: While these techniques may seem far removed from interpretive approaches, they suggest that "texts" can be viewed in a far less traditional sense than is typically the case. In our own work, we have employed a number of prompts to elicit texts from our participants. One such technique, used by Palmquist (1990) towards the end of his study, provides the basis for a more confirmatory approach to interpreting mental models. This technique, the "concept circle," involves arranging a set of pre-identified concepts in a circle on a page and asking participants to, essentially, connect the dots -- i.e., to draw lines between terms that they believe are related. Figure 3 is a concept circle similar to that used by Palmquist with three relationships filled in corresponding to the information in lines 9 and 10 in Figure 2. The phrase "Decide specifically what you are going to write down" gets translated as a relationship between topic and writing. Similarly, the phrase "which side of the issue or something" gets translated as a relationship between issue and sides. And finally, going from line 9 to 10 there is an implied relationship



between topic and issue.

Figure 3. Concept Circle

The concept circle, when used in conjunction with other methods, such as interviews and written responses, can supply information concerning relationships that might not otherwise be available to the researcher. Unlike interviews, for instance, the concept circle encourages the participants to make explicit relationships that they might otherwise treat as tacit social knowledge. Moreover, techniques such as the concept circle can act as prompts to produce additional texts. For instance, the concept circle could be completed during an interview and the interviewer could ask specific questions concerning the nature of the relationships that the respondent sees between each pair of concepts. We have found that placing concepts in a circle works better than placing them in two side-by-side lists as when the latter format is used subjects often neglect to put lines between concepts in the same column.

While techniques such as the concept circle would typically be seen as the outgrowth of a confirmatory approach to identifying concepts, it might also be used in a more exploratory approach. Unlike more open-ended prompts, however, it is inherently limited in the number of statements it can elicit from a given participant. Further, there are practical limitations to the number of concepts that can be placed in a concept circle. These follow from the fact that there is a combinatorial explosion of possible statements as the number of concepts increases. Palmquist found that the practical upper limit on the number of concepts that could be considered in a session lasting between 20 and 40 minutes appeared to be between 30 and 40.

Using ***CODEMAP***

Once ***STARTUP*** has been used to create a template file and texts have been collected, the researcher can employ ***CODEMAP*** to encode the extracted statements. This coding process can alter the template file if, for example, the researcher while coding a text adds new concepts to a category. Following is an interchange between the program ***CODEMAP*** and the researcher that illustrates the entry of the three statements in Figure 3. In this example, the software's response is in bold, the researcher's response is in plain text, and annotated explanations are in italics. Further, in this example, we have assumed that all of the concepts shown in Figure 3, except topic, have already been added to the template file.

WELCOME TO CODEMAP V4

Copyright (c) 1990 Carley

What is the name of the set-up file? mysetup.dat _ *the template file*

What is your name? coder _*full name, initials, or any id*

What is the date? 3/90

What is the name of the text? (one word) student _*must be one word*

Output will be put into the file student.map. _ *map is automatically appended*

Directions? (y/n) n

Concept? (<concept name>, #, <cr>, ?, or -quit) ? _*a "?" always causes CODEMAP to print help if it exists*

For each sentence you may have 1 or more Concepts. First check to see if the Concept is already in the list of Concepts If it is, then all you need to type is the first word or unique characters If it is not, then type the entire phrase. A '#' will print out a list of the available Concepts in category book2. A -quit returns you to the question -

CONTINUE? A carriage return <cr> acts like a quit. _*CODEMAP is automatically modified by the template file. Note the use of "book2" for concept category.*

Concept? (<concept name>, #, <cr>, ?, or -quit) wri _*you need not type in the complete concept only the first few unique characters*

Do you want the Concept: writer? (y/n) n

Do you want the Concept: writing? (y/n) y

Concept? (<concept name>, #, <cr>, ?, or -quit) topic _ *can be multiple words*

topic is not listed as a Concept of type concept

Do you want to add topic to the Concept list? (y/n) y

The Concepts are:

(1) topic

(2) writing

Current Information:

strength No Relation

directionality bi-directional -- directionality can not be altered

Do you wish to change any of this information? (y/n) y _*since the only choice is to change the strength, no-relation will automatically be changed to presence of relation*

CONTINUE? (y/n) y

Concept? (<concept name>, #, <cr>, ?, or -quit) issue

Do you want the Concept: issue? (y/n) y

Concept? (<concept name>, #, <cr>, ?, or -quit) sides

Do you want the Concept: sides? (y/n) y

The Concepts are:

(1) issue

(2) sides

Current Information:

strength No Relation

directionality bi-directional -- directionality can not be altered

Do you wish to change any of this information? (y/n) y

CONTINUE? (y/n) y

Concept? (<concept name>, #, <cr>, ?, or -quit) topic

Do you want the Concept: topic? (y/n) y **_** *the template file has now been changed and includes the concept topic*

Concept? (<concept name>, #, <cr>, ?, or -quit) issue

Do you want the Concept: issue? (y/n) y

--

The Concepts are:

(1) topic

(2) issue

Current Information:

strength No Relation

directionality bi-directional -- directionality can not be altered

Do you wish to change any of this information? (y/n) y

CONTINUE? (y/n) n

Thank you for coding this text.

The output will be in the file student.map.

Do you wish to code another text? (y/n) n

THANK YOU FOR USING CODEMAP

The contents of the output-file student.map are:

created by coder 3/90:

1$book2$issue$book2$sides$2

1$book2$issue$book2$topic$2

1$book2$sides$book2$issue$2

1$book2$topic$book2$issue$2

1$book2$topic$book2$writing$2

1$book2$writing$book2$topic$2

Although we have illustrated this process by first placing lines on the concept circle to denote relationships between concepts in the text and then using ***CODEMAP*** there is no reason, if one has a text, to construct the concept circle as an intermediate step. In the following example, lines 1,2, and 3 in Figure 2 are coded directly.

The student says to get a topic (line 1) and defines this in terms of what is going to be written on (line 2). This implies a relation between the concepts topic and writing which can be coded as:

Concept? (<concept name>, #, <cr>, ?, or -quit) topic

Do you want the Concept: topic? (y/n) y

Concept? (<concept name>, #, <cr>, ?, or -quit) writing

Do you want the Concept: writing? (y/n) y

--

The Concepts are:

(1) topic

(2) writing

Current Information:

strength No Relation

directionality bi-directional -- directionality can not be altered

Do you wish to change any of this information? (y/n) y

CONTINUE? (y/n) y

The student next says that to go to the library and find out something about it (line 3). The "it " must be referring to topic. So this contains information on a relationship between library and find, and between find and topic. These can be coded as:

Concept? (<concept name>, #, <cr>, ?, or -quit) library

Do you want the Concept: library? (y/n) y

Concept? (<concept name>, #, <cr>, ?, or -quit) find

Do you want the Concept: find? (y/n) y

--

The Concepts are:

(1) library

(2) find

Current Information:

strength No Relation

directionality bi-directional -- directionality can not be altered

Do you wish to change any of this information? (y/n) y

CONTINUE? (y/n) y

Concept? (<concept name>, #, <cr>, ?, or -quit) find

Do you want the Concept: find? (y/n) y

Concept? (<concept name>, #, <cr>, ?, or -quit) topic

Do you want the Concept: topic? (y/n) y

The Concepts are:

(1) find

(2) topic

Current Information:

strength No Relation

directionality bi-directional -- directionality can not be altered

Do you wish to change any of this information? (y/n) y

CONTINUE? (y/n) y

In addition, there is an implied relation between topic and library, which can be coded as:

Concept? (<concept name>, #, <cr>, ?, or -quit) library

Do you want the Concept: library? (y/n) y

Concept? (<concept name>, #, <cr>, ?, or -quit) topic

Do you want the Concept: topic? (y/n) y

The Concepts are:

(1) library

(2) topic

Current Information:

strength No Relation

directionality bi-directional -- directionality can not be altered

Do you wish to change any of this information? (y/n) y

CONTINUE? (y/n) y

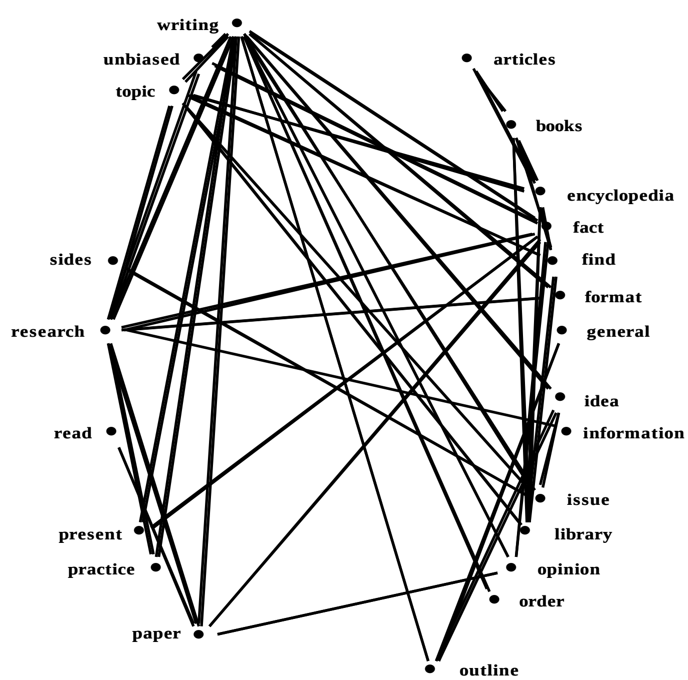
This process can continue until the entire interview is coded.

In the foregoing examples we have used a very simple template, indeed it is the simplest possible template. Had we made other coding decisions when we characterized the relationships or had we used multiple concept categories not only would the template file have been more complex but the questions asked by ***CODEMAP*** would also differ from those shown here. A more complex template and its effect on ***CODEMAP*** are demonstrated in Appendix 2. In addition the reader is directed to (Carley, 1988) for examples of more complex maps.

Step 4: Display and Analyze

The final step is to display and analyze the resultant maps. Maps can be displayed and analyzed using the same procedures regardless of what combination of confirmatory and exploratory perspectives were taken in the previous three steps. It is beyond the scope of this paper to provide extensive detail on how to analyze these maps. However, we will provide general guidelines that indicate the types of analyses in which the researcher can engage. An advantage of using this computer-assisted approach is that the data can be analyzed both visually using map display procedures and numerically using statistical procedures.

When maps have fewer than 100 concepts they can be displayed using the program DRAWMAP. (The maps are easier to view, however, if there are fewer than 40 concepts.) DRAWMAP places the concepts in the coded map around a circle[8] and then, using the information on the relationships, places lines between the concepts. Directionality can be denoted by arrows on the lines, and strength can be denoted by placing a number on the line. Since in the examples that follow, all relationships are bi-directional and have the same



strength, we have simplified the graph by only putting a line between the connected concepts.

Figure 4. Example Map For Student - Interview 1, Beginning of Term

Figure 4 is a graphic illustration of the complete map extracted from the complete interview with a student at the beginning of the term (from which the text in Figure 2 was drawn). All concepts in the map are listed in a circle. The relationship between two concepts is denoted by a line. This map represents the student's conception of research writing at the beginning of the term. This map illustrates that those concepts about which the student has the most information at the beginning of the term are fact, research, topic, and writing. Tracing through some of the relationships (represented by lines) between concepts reveals that in the student's view, at the beginning of the term, writing a paper involves having an opinion which is based on fact which can be found through research.

Figure 5 is a graphic illustration of the map extracted from an interview with the same student later in the term. Portions of this later interview are in Appendix 1. This represents the student's conception of research writing at the end of the term. Visual comparison of Figure 4 and Figure 5 shows that the student's conception has shifted over time. For example, many of the concepts used by the student to describe research writing have changed and, for those concepts that are retained, their relative semantic importance may have changed (more important, more relationships, more lines). From the beginning to the end of the term, in the student's mental model of research writing, the concept information has grown in importance (more lines in Figure 5 than 4) but the concept outline has decreased in importance to the extent that it doesn't even appear in the later map. Once again tracing through some of the relationships between concepts reveals that in the student's view, at the end of the term, writing a paper involves having information which depends on facts and a plan which is original and guides research.

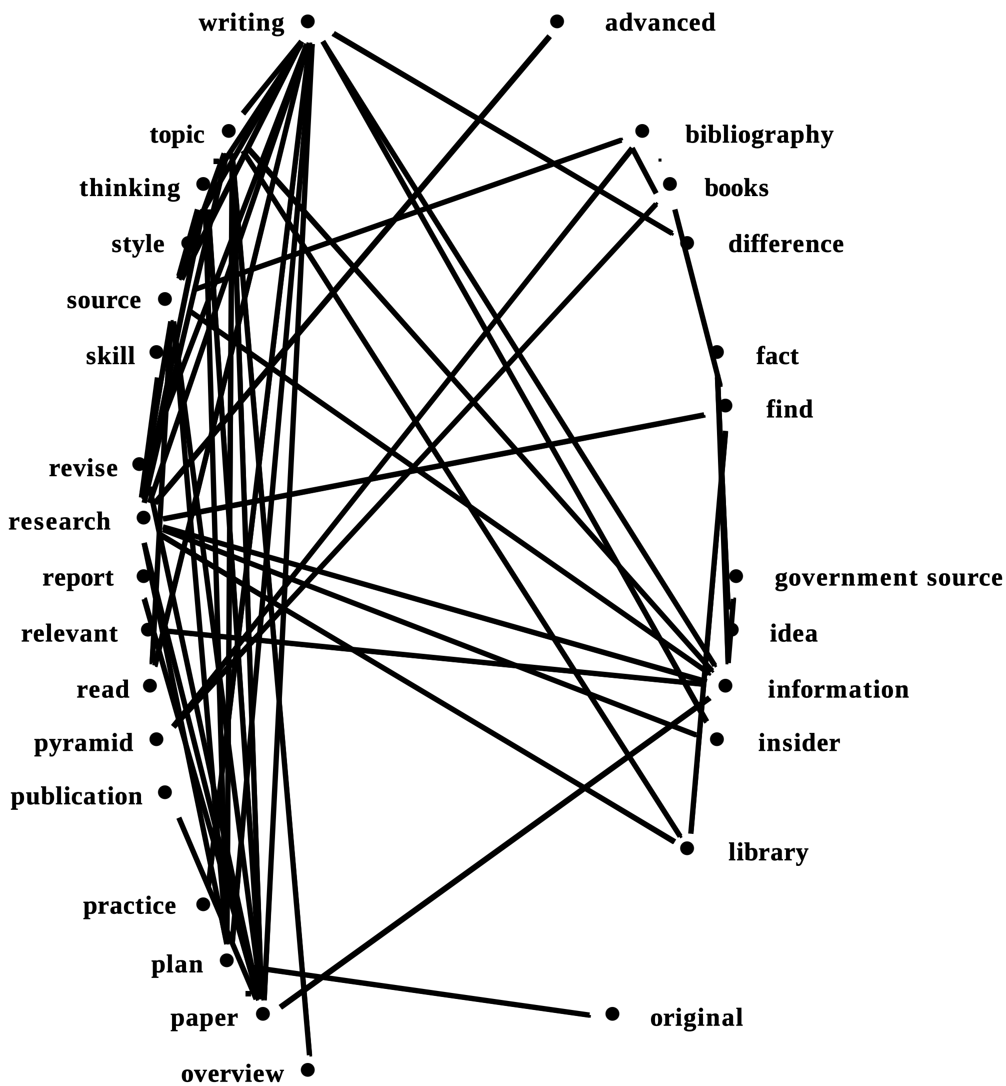


Figure 5. Example Map For Student - Interview 2, End of Term

In addition to graphic representations, maps can be analyzed statistically. For example, when multiple maps are coded using the same startup file the researcher can compare these maps in terms of the number and similarity of concepts and statements. Table 1 shows a statistical comparison of two maps shown in Figures 4 and 5.[9] This data suggests that over the course of the term the student's conception of research writing has expanded (number of concepts increased from 23 to 29 and the number of statements from 84 to 110) but has become more disjointed (density decreases as the average number of concepts per statement decreased from 0.27 to 0.26). Since well understood concepts are usually part of a very dense map this result suggests that, though having taken the course, the student may still not understand the subject matter.

Table 1. Statistics Comparing Student's Maps from the Beginning and End of the Term

Category	Number of Concepts	Number of Statements
Beginning Map	23	84
Ending Map	29	110
Both Beginning and Ending Map	12	20
Only in Beginning Map	11	64
Only in Ending Map	17	90

Such statistical analysis is particularly important if the researcher wants to contrast maps that are too big to be conveniently displayed graphically. For example, the map of the instructor's mental model of research writing (Appendix 1) contains more than 150 concepts. However, statistically, we can still address the question -- "Does the student's mental model come to emulate the instructor's over the course of the term?" Table 2 shows the relationship between the student's map at the beginning and the end of the term and the instructor's map. This data suggests that not only did the student's map become more complex, but it did so, in part, by acquiring more of the instructor's knowledge. That is, the number of concepts and statements shared between the student and instructor increased over time. If we think of the information in the student's map that is not in the instructor's as possible errors in what the student knows then this data also suggests that the student's map may have become more complex because the student was mis-learning (increase in number of concepts and statements that are only in the student's map). Further, the greater increase in erroneous statements than concepts suggests that the student had basically learned the right vocabulary but not what that vocabulary really means. The student may have used all the right jargon, but did so in inappropriate ways.

Table 2. Statistics Comparing Student's Maps with the Instructor's Map

Category	Number of Concepts		Number of Statements	
	Beginning	Ending	Beginning	Ending
Student Map	23	29	84	110
Instructor Map	211	211	1059	1059
Both Student and Instructor Map	17	22	8	18
Only in Student Map	6	7	76	92
Only in Instructor Map	194	189	1051	1041

DISCUSSION

The procedures for extracting, representing, and analyzing mental models that we have described are quite general and can be used in a number of applications. Potential applications of these procedures include, but are not limited to, comparisons of experts and novices, explorations of shared knowledge, and studies of longitudinal change. Each of these applications would employ the procedures we have discussed above in divergent, though potentially complementary ways. In expert/novice comparisons, for instance, the investigator would be likely to focus largely on differences in the content and structure of the mental models of experts and novices. In contrast, explorations of shared knowledge would more likely focus on similarities between individuals. Longitudinal studies, with their emphasis on change over time, would tend to focus on changes that occur within individuals and groups. In each case, the procedures we have presented here can provide the basis for a consistent and theoretically grounded approach to the quantitative study of mental models.

Our illustrations have shown that the proposed techniques have a wide range of applicability. Nevertheless, applying these techniques, as is true for most naturalistic approaches, is a time-consuming process. Use of ***CODEMAP*** does reduce coding time and facilitates statistical analysis (Carley, 1988). We expect, however, that the process can be further automated. Possible approaches include utilizing expert systems (Carley, 1988) for augmentation, windowing techniques for locating physically proximal words (Danowski, 1982, 1988), and linguistically based approaches for locating relationships between concepts (Gottschalk, Hausmann and Brown, 1975; Roberts, 1987). There are difficulties with all of these approaches. The augmentation approach requires the existence of a set of shared social knowledge. The windowing approach assumes that just because words are used in proximity they are related, and ignores distinctions in meaning such as John loves Mary and John hates Mary. As a result, relationship information such as directionality, strength, and type are generally lost. And methods that focus on syntax are generally difficult to automate and tend to oversimplify semantic relationships. Thus, for now, the computer-assisted approach for extracting mental models like that used in this paper seems the best solution.

CONCLUSION

The process presented in this paper for extracting, representing, and analyzing mental models expands our repertoire of methods for assessing the mental models of individuals and, by extension, the shared knowledge of social groups. We find this methodology particularly useful because it allows the researcher to compare and contrast the mental models of different individuals, locate information that is shared by members of a group, and determine ways in which knowledge possessed by specific individuals differs from knowledge that is shared by "most" of the members of a particular group. Further, this approach admits such comparisons in a way that allows the investigator to retain both a rich verbal description of what is said that can be used along with other qualitative methods and is sufficiently consistent across group members that a quantitative analysis can be carried out. Finally, because this set of procedures allows the investigator to automate a number of aspects of data collection and analysis, it offers advantages over the process-based measures used in purely qualitative approaches such as protocol analysis of in-depth interviews, case-study observations, and general ethnographic procedures.

NOTES

1 By verbal structure we are referring to the inherent semantic structure, the concepts, and the relations between these concepts, rather than to the syntactic structure of the text.

2 In earlier work, statements have been referred to as facts (Carley, 1986a, 1986b, 1988;Minsky, 1975) or as associations (Palmquist, 1990). In contrast to these earlier studies, we use the term statement in order to make it clear that what we are talking about is simply a piece of information and not an item with a particular truth value.

3 A more detailed version of this appendix is available from the first author upon request.

4 At a theoretical level maps can be disaggregated into types (Carley, 1988). Herein, we take a more operational stance and simply use the term map to denote an interrelated set of statements.

5 Depending how one identifies concepts and relationships, these networks may be semantic networks (Schank and Colby, 1973), augmented transition networks (Winston, 1977), conceptual networks (Sowa, 1984), socio-cognitive networks (Krackhardt, 1987; Krackhardt and Kilduff, 1990), and so on.

6 The automated tools can run on UNIX workstations, many IBM personal computers or clones, and Apple Macintosh Computers. They are available upon request from the first author.

7 Whether this change necessitates recoding all maps depends on the nature of the change. In general, deleting categories and altering the strength of relationships necessitates recoding.

8 There are procedures to allow the user to order the concepts and use abbreviations instead of full concept names.

9 Software exists for doing the statistical procedures described above and is available from the first author. In addition, for a set of maps, a binary matrix can be constructed indicating which concept (or statement) is present in which map. This matrix can then be analyzed using standard statistical procedures such as cluster analysis.

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APPENDIX 1: SIMPLE TEMPLATE EXAMPLE

This data is drawn from Palmquist (1990). It is divided into four parts: 1) the template file coded using ***STARTUP*** as it stood at the end of the analysis, 2) two different interviews with the same student one at the beginning of the term and one at the end of the term, 3) the maps extracted from each of these interviews, and 4) the map extracted from the expert (i.e., course instructor). In all cases, only excerpts from these files are included.

TEMPLATE FILE

This files contains 244 concepts, only 20 of which are shown here.

1 Concept Types	244 Total Concept	. . .	. . .
book2	244 book2	interview	visualize
2 Link Types	book2	introduction	works cited
strength	APA	intuition	writer
directionality	CDROM	issue	writing
2 directionality	LIS	journals	yearbook
1 Minimum	MLA	. . .	
Strength	PittCat	research	
1 Maximum	abstract	research paper	
Strength	accuracy	researcher	

EXAMPLE DATA

<u>Interview 1 - Student Beginning of Term</u>

The full interview contains 23 exchanges between the interviewer and the student, only 9 of which have been reported here.

Interviewer: Tell me what you know about research writing.

Student: Not much. I don't know anything about it in terms of format. It just depends on our teacher, our English teacher said "as long as it is consistent I don't care what you do". I've only done one or two real research papers, and I have absolutely no idea about how to do them. So I took this class...

Interviewer: What do you mean by "format"?

Student: How it is written out, how it is presented.

Interviewer: Suppose you are in class, and get an assignment to write a research paper, and somebody asks you what a research paper is -- what are you going to tell them?

Student: Ask some of my neighbors to help (laughs)! Ah, do some research and write a paper about it.

Interviewer: What would you do, what steps would you go through to write one?
Student: I have a horrible time with research writing. I have trouble getting facts, and stuff, that's the reason why I am taking the class...
--- Excerpt in Figure 2 Went Here ---
Interviewer: So you do take a position. And after you've done that you say you have an outline.
Student: No so much an outline, its more like writing down some of the things you might want to write, jotting down in no particular order.
Interviewer: ?? And then after you have all of those things down, what then?
Student: Lock yourself in a closet for four days and try to write the stupid thing.
...
Interviewer: A variety of factors may affect your writing etc... What factors are the most influential in affecting your research writing.
Student: I am really bad at practice ?? so actually doing it is what most helps me.
Interviewer: How does research writing differ from other types of writing, like writing a novel?
Student: It's made up, a novel. Research writing is supposed to be an unbiased account or presentation of the facts you have, whereas a novel is anything you want it to be.
Interviewer: Okay, want to add anything about research writing in general?
Student: No.

<u>Interview 2 - Student End of Term</u>

The full interview contains 25 exchanges between the interviewer and the student, only 7 of which have been reported here.

Interviewer: tell me what you know about research writing.
Student: How to do it, or what it's used for or ...
Interviewer: Well why don't you talk about ... talk about what it is and what you would do, you know, the steps you do, and things like that, the techniques you'd use . . .
Student: Okay. Um... research writing is writing to find out something and convey it to other people and to do that you'd find out something and then convey it to other people. You'd like ... you'd have your source or whatever, I mean your topic, not really your source, and you find sources on your topic and all the relevant information and write it into a paper and publish it.
Interviewer: Okay. How would you go about finding this information?
Student: Um... well, that depends on the topic. You know, you start at the library and you look in encyclopedias and whatever if it's something you're not really familiar with and, ah, you know, finding books and using the pyramid method from the bibliographies of the books. A lot of things you write away to various things for information on them, to the societies for information or the government thing, or, you know, like anything.
...
Interviewer: Okay. How do you think your approach to research writing might differ from that of other writers?

Student: Just different ways of thinking and different views on what's important, different views on what people want to hear.

Interviewer: Yeah. Okay. Um... I actually had two questions there, this is more, this is refining the whole line of questions I've already been asking, but what specific approaches, resources, or techniques do you draw on when you're actually writing a research paper?

Student: Um... yeah. The pyramid method thing, um. I always ask people if they've read anything on it, you know, that kind of stuff.

...

Interviewer: Once you actually sit down and you're writing, what do you do? Do you just look at your ... (garbled) ...

Student: Yeah. Kind of. Like, the paper I did, which is this one. Most of it was just writing from my mind. I mean, it wasn't really stuff I found in sources. It was stuff I came up with, or stuff like that. So, I just kind of sat and tried to get something on paper and, like, I rewrote, I think I rewrote my opening paragraph six times.

Interviewer: Yeah. So then once you get the opening paragraph done you just . ..

Student: Well, I rewrote the opening paragraph four times before I started and didn't like any of them and then went ahead and wrote the whole thing, then, eventually, I rewrote the opening paragraph. Actually, I had the whole thing done. I went through it, just like read it and revised it about three times. And I still didn't like it. So, I just sat down, this is basically what I did last night, I just sat down and I went through paragraph by paragraph, a sentence at a time reading it out loud and changing it, and just stayed until I liked it.

...

EXAMPLE MAPS

<u>Interview 1 - Student Beginning of Term</u>

The complete map contains 84 statements only 24 of which have been reported here.

mike 11-28-89:: mod on 11-28-89, mike:
1$book2$articles$book2$encyclopedia$2
1$book2$articles$book2$books$2
1$book2$encyclopedia$book2$articles$2
1$book2$encyclopedia$book2$library$2
1$book2$encyclopedia$book2$topic$2
. . .
1$book2$topic$book2$encyclopedia$2
1$book2$topic$book2$issue$2
1$book2$topic$book2$library$2
1$book2$topic$book2$research$2
1$book2$topic$book2$writing$2
1$book2$topic$book2$find$2
. . .

1$book2$writing$book2$fact$2
1$book2$writing$book2$format$2
1$book2$writing$book2$idea$2
1$book2$writing$book2$issue$2
1$book2$writing$book2$opinion$2
1$book2$writing$book2$outline$2
1$book2$writing$book2$paper$2
1$book2$writing$book2$present$2
1$book2$writing$book2$research$2
1$book2$writing$book2$topic$2
1$book2$writing$book2$unbiased$2
1$book2$writing$book2$order$2
1$book2$writing$book2$practice$2

Interview 2 - Student End of Term

The complete map contains 110 statements only 29 of which have been reported here.

mike 11-29-89:: mod on Dec 15 1989, mike:
1$book2$advanced$book2$research$2
1$book2$bibliography$book2$books$2
1$book2$bibliography$book2$pyramid$2
1$book2$bibliography$book2$source$2
1$book2$books$book2$bibliography$2
1$book2$books$book2$find$2
1$book2$books$book2$pyramid$2
. . .
1$book2$topic$book2$information$2
1$book2$topic$book2$library$2
1$book2$topic$book2$overview$2
1$book2$topic$book2$paper$2
1$book2$topic$book2$plan$2
1$book2$topic$book2$research$2
1$book2$topic$book2$source$2
1$book2$topic$book2$thinking$2
1$book2$topic$book2$writing$2
1$book2$writing$book2$difference$2
1$book2$writing$book2$information$2
1$book2$writing$book2$insider$2
1$book2$writing$book2$paper$2
1$book2$writing$book2$plan$2
1$book2$writing$book2$practice$2
1$book2$writing$book2$read$2
1$book2$writing$book2$research$2
1$book2$writing$book2$revise$2
1$book2$writing$book2$source$2
1$book2$writing$book2$style$2
1$book2$writing$book2$thinking$2
1$book2$writing$book2$topic$2

EXAMPLE MAP - INSTRUCTOR

The complete map contains 1059 statements only 34 of which have been reported here.

mike Sep 26 1989:: mod on Sep 26 1989, mike:
1$book2$APA$book2$MLA$2
1$book2$APA$book2$bibliography$2
1$book2$APA$book2$citation$2
1$book2$APA$book2$format$2
1$book2$APA$book2$reference list$2
1$book2$APA$book2$research paper$2
1$book2$APA$book2$revise$2
1$book2$APA$book2$style manual$2
1$book2$APA$book2$works cited$2
. . .
1$book2$author$book2$card catalog$2
1$book2$author$book2$expert$2
1$book2$author$book2$insider$2
1$book2$author$book2$reference list$2
1$book2$author$book2$source$2
1$book2$author$book2$subject$2
1$book2$author$book2$summary$2
1$book2$author$book2$title$2
1$book2$author$book2$works cited$2
. . .
1$book2$topic$book2$background$2
1$book2$topic$book2$data$2
1$book2$topic$book2$expert$2
1$book2$topic$book2$focus$2
1$book2$topic$book2$issue$2
1$book2$topic$book2$library$2
1$book2$topic$book2$prospectus$2
1$book2$topic$book2$question$2
1$book2$topic$book2$research$2
1$book2$topic$book2$source$2
1$book2$topic$book2$subject$2
1$book2$topic$book2$subject matter$2
1$book2$topic$book2$subtopics$2
1$book2$topic$book2$title$2
1$book2$topic$book2$trim$2
. . .
1$book2$writing$book2$report$2

APPENDIX 2: MORE COMPLEX TEMPLATE EXAMPLE

This data is drawn from Carley (1984). It is divided into three parts: 1) the session with ***STARTUP*** in which coding decisions are set, 2) a portion of an interview with a student annotated with information on what concepts are present, 2) a portion of a session with ***CODEMAP*** in which the first 3 statements from the interview are coded.

Session with *STARTUP*

Carley (1984) took an exploratory approach to concept identification, used four categories of concepts, used a range of strengths to denote positive and negative relationships as well as emphasis, used both uni- and bi-directional relationships, but did not define any special type of relationships. Following is an interchange between the program ***STARTUP*** and the researcher that illustrates the entry of this set of decisions. In this example, the software's response is in **bold**, the researcher's response is in plain text, and annotated explanations are in *italics.* The result of this process is a template file that will control the future operation of other software.

WELCOME TO STARTUP V4
Copyright (c) 1990 Carley

This program is used to enter the set-up information
used by the following MECA programs -- CLIST, CMATRIX, CODEMAP, COMPRA, CUBE, SCOMPRA, SKI, SMATRIX

This program is entirely interactive.
A series of questions will be asked.
After answering the question simply type a carriage return.

The output file is an asci file.

What would you like to call the file containing the set-up information?
??? 3esetup.dat

You can classify concepts into a maximum of 9 categories
How many concept categories are there?
??? 4

Name of concept category 1? Aspects
Name of concept category 2? Requirements
Name of concept category 3? Facts
Name of concept category 4? Qualities

Are statements:
1) Some uni- and some bi- directional

2) All uni-directional
3) All bi-directional
??? 1

Are you using strength:
1) To denote existence
2) To denote existence and sign
3) A range of strengths
4) Number of occurrences of this statement
??? 3

What is the minimum strength? -3
What is the maximum strength? 3

You can classify relationships (links) into a maximum of 9 types
How many types of links are there?
??? 0

How many concepts in category Aspects do you currently have? 4
How many concepts in category Requirements do you currently have? 0
How many concepts in category Qualities do you currently have? 0
How many concepts in category Facts do you currently have? 0

List concepts in category Aspects
??? Social
??? Academic
??? Practical
??? Administrative

THANK YOU FOR USING STARTUP
Your data is being stored in the file 3esetup.dat.
It can be edited with a standard text editor.

Annotated Interview of Johann During Time 1

Following is a portion of an interview with the student Johann at the beginning of the tutor selection process. In annotating this interview segment the text of the interview is on the left, and the extracted concepts are on the right. Each concept is marked as to whether it is an [A] aspect, [R] requirement, [F] fact, or a [Q] quality. Portions of this same interview are also presented in Carley, 1988. Indented concepts are linked to the one above with the strength shown. A strength range of -3 to 3 is used. A strength of -1 or 1 means that the relationship is inferred by the researcher. A strength of -2 or 2 means that the relationship is present in the text even though the concepts being coded may be generalized versions of the ones actually present in the text. A strength of -3 or 3 means that the author of the text emphasizes the relationship.

Interviewer: If you were going to do the selection process by yourself how would you do it

Student: well does this predicate my being selected
as a representative or am I just making irrelevant
this decision for a personal *tutor*

Interviewer: you're selecting a hall *tutor*, but you are in charge to do what ever you want

Student: well I would certainly take some accounting of you know,
what I think would be
too objectionable to most people [F] number of students ok TC
[A] Social
[R] fits in with hall
2 [F] number of students ok TC

but any person,
that I thought would be **reasonable** [Q] tolerant,reasonable
you know, that could
get along with the majority of the hall [R] friendly,gets along
[F] number of students ok TC
[A] Social
2 [R] friendly,gets along
2 [F] number of students ok TC
2 [Q] tolerant, reasonable
1 [R] fits in with hall
2 [F] number of students ok TC
2 [Q] tolerant, reasonable
[F] number of students ok TC
1 [Q] tolerant,reasonable

and f**ulfill whatever obligations** [R] capable of doing the job
t**here are along with the position** presumably is referring to
the ability to *tutor*
[A] Practical
2 [R] capable of doing the job
1 [R] academic counsel,teaching ability
[A] Academic
1 [R] capable of doing the job
1 [R] academic counsel,teaching ability

I would tend to try to find someone
that I thought was **interesting,** [R] interesting
[Q] inspiring,unusual,interesting

which, recognizing all the while,
that **my idea of an interesting person** [F] number of students share interest

is not every one else's

[A] Social
2 [R] interesting
2 [F] number of students share interest
2 [Q] inspiring,unusual,interesting

Session with *CODEMAP*

WELCOME TO CODEMAP V4

Copyright (c) 1990 Carley

What is the name of the set-up file? 3esetup.dat
What is your name? coder
What is the date? 3/90
What is the name of the text? (one word) johan1
Output will be put into the file johan1.map.

Directions? (y/n) n

Is **the Concept in category:**
1) Aspects
2) Requirements
3) Facts
4) Qualities
??? 2
Concept? (<concept name>, #, <cr>, ?, or -quit) fits
Do you want the Concept: fits in with hall? (y/n) y

Is the Concept in category:
1) Aspects
2) Requirements
3) Facts
4) Qualities
??? 1
Concept? (<concept name>, #, <cr>, ?, or -quit) S
Do you want the Concept: Social? (y/n) y

The Concepts are:
(1) fits in with halll
(2) Social

Current Information:
    strength   No Relation
    directionality   No Information

Do you wish to change any of this information? (y/n)   y
new strength? (between -3 and 3 or NI (NI deletes statement))   1
Is the relationship between these Concepts
    1) uni-directional from 1 to 2
    2) bi-directional
???   1

CONTINUE? (y/n)   y

Is the Concept in category:
    1) Aspects
    2) Requirements
    3) Facts
    4) Qualities
???   2
Concept? (<concept name>, #, <cr>, ?, or -quit)   fits
Do you want the Concept: fits in with hall? (y/n)   y

Is the Concept in category:
    1) Aspects
    2) Requirements
    3) Facts
    4) Qualities
???   3
Concept? (<concept name>, #, <cr>, ?, or -quit)   number
Do you want the Concept: number of courses taken? (y/n)   n
Do you want the Concept: number of students ok TC? (y/n)   y

--

The Concepts are:
    (1) fits in with hall
    (2) number of students ok TC

Current Information:
    strength   No Relation
    directionality   No Information

Do you wish to change any of this information? (y/n)   y
new strength? (between -3 and 3 or NI (NI deletes statement))   2
Is the relationship between these Concepts
    1) uni-directional from 1 to 2

2) bi-directional
??? 2

CONTINUE? (y/n) n

Thank you for coding this text.
The output will be in the file johan1.map.
Do you wish to code another text? (y/n) n

THANK YOU FOR USING CODEMAP