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**University Professors' and Students' Knowledge  
of The Executive Control Strategies  
Applied in The Solving of Ill-structured Problems**

**by**

**K. Lynn Taylor**

**Thesis submitted to the School of Graduate Studies  
of the University of Ottawa  
in partial fulfilment of the requirements  
for the degree of Doctor of Philosophy in Education**

**Ottawa, Canada, 1992**

• **K. Lynn Taylor, Ottawa, Canada, 1992**



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**Dedicated**

**to my husband, Ken,**

**whose unwavering support and confidence**

**have been a constant in the variable processes**

**of study and research**

**and to my children, Keith and Karin,**

**who continue to inspire my commitment to education.**

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People become educated, as against trained, in so far as they achieve a grasp of the principles of critical thought and the motivation to choose, organize and assess their own ideas by means of them. Education is not a mere piling up of more and more bits and pieces of information. It is a process of deciding for ourselves what we do and do not know. It implies a self-motivated action upon our thinking and a participation in the forming of our own character. It is a process in which we learn to open our mind, to correct and refine it, to enable it rationally to learn; thus to empower it to analyze, digest, and rule its own knowledge, to gain command over its own faculties, to achieve flexibility, fairmindedness, and critical exactness.

Richard W. Paul (1987)

## **Abstract**

In a problem solving context, executive control (EC) strategies are those strategies which monitor, direct and evaluate the problem solving process. Effective use of EC strategy knowledge characterizes the problem solving behaviour of expert solvers, but is commonly lacking in students. The exploratory investigation presented here addresses EC strategy knowledge at the university level and was guided by the following research objectives: (1) to explore EC strategy use and the associated strategic knowledge demonstrated by professors and students, while solving ill-structured problems within their domain of expertise and outside of that domain; and (2) to examine the differences in EC strategies applied and in associated strategic knowledge, across expertise and across domains. The research describes a broader range of EC strategy knowledge than is typically addressed in conventional expert-novice studies. This broader spectrum of strategy knowledge is reflected in a model of strategy knowledge first proposed by Pressley, Borkowski and O'Sullivan (1985) which, in its revised form, includes the interaction of general strategy knowledge, specific strategy knowledge and strategy acquisition knowledge.

Four groups consisting of nine students and nine professors from the domain of biology and nine students and nine professors from the domain of political science respectively, were recruited on a volunteer basis. Following a short training session, each solver was requested to solve randomly assigned, ill-structured tasks in two domains: biology and political science. Participants were asked first, to work on each task while thinking aloud and then, to report on how they solved the problem in a

semi-structured interview. All verbalizations were audiotaped, transcribed and then coded to extract EC strategy knowledge.

The results indicate clear expertise and domain differences. Across expertise, professors and students differed in their patterns of global strategy use, the specific strategy knowledge they demonstrated and the beliefs they reported relevant to problem solving. Some of these results reflected a non-linear progression from novice to expert, suggesting that the EC strategy knowledge of both professors and effective student solvers provide an important resource in understanding and addressing EC strategy knowledge in the context of academic courses. Across domains, general strategy knowledge differences were strongest and influenced specific strategy knowledge, which in turn, was frequently implemented with different emphases and supported by different conditional knowledge. At a more general level, a number of themes emerged from the data. As expected, a full spectrum of EC strategy knowledge was demonstrated in the strategy knowledge reported by university students and professors, and the components of strategy knowledge in this spectrum were inter-dependent. The results on strategy acquisition knowledge indicated that solvers experienced little exposure to strategic knowledge in academic courses. Consequently, there was little conscious awareness of how EC strategy knowledge can be actively acquired. Finally, a performance-goal pattern of motivation was observed to influence the problem solving behaviour and strategy acquisition knowledge of both professors and students.

The results have important implications for how university level educators represent and use EC strategy knowledge in their classrooms and demonstrate specific forms of EC strategy knowledge which could contribute to the development of "competence" in the domains of biology and political science.

## **CHAPTER 1**

### **THE PROBLEM**

The ability of university students to reason and solve problems is a source of serious concern to teaching faculty. Although the development of problem solving ability is an educational objective which is highly valued by professors, students and society in general (e.g. Aikenhead, 1980; Voss, Perkins & Segal, 1991), it remains an objective which is not often realized. University students frequently perform well on memory and comprehension tasks, and can competently solve problems similar to those discussed in class. These same students, however, experience difficulty with learning tasks which require the use of conceptual knowledge in new situations or the application of problem solving strategies. These difficulties have been reported in varied domains including biology (e.g. Smith & Good, 1984); education (e.g. Arons, 1976,; 1984); mathematics (e.g. Schoenfeld, 1983; 1985); physics, (e.g. Larkin, 1980); political science (e.g. Voss, Greene, Post & Penner, 1983) and writing (e.g. Flower, Hayes, Carey, Schriver & Stratman, 1986). The problem is compounded by the interplay of motivation and ability (Borkowski, Johnston & Reid, 1986), so that even if students have acquired problem solving strategies, their use is often inconsistent (Donald, 1985).

These domain-based findings regarding problem solving behaviour are supported by research conducted in a Piagetian framework which indicates that up to fifty percent of university level students do not function at a formal operations stage (e.g. Chiapetta, 1976; Kolodiy, 1975; Poduska & Phillips, 1986; Renner & Lawson, 1975). In performance terms, this finding implies that up to one-half of a broad cross-section of

university undergraduates are likely to have difficulty in generalizing concepts and applying problem solving strategies in new situations (Nickerson, Perkins & Smith, 1985), dealing with hypothetical situations (Fuller, 1980) or perceiving the interplay of ideas and actions (Duly, 1978). Most simply put, these students often perform poorly on tasks requiring the application of theoretical knowledge to problem situations (Polson & Jeffries, 1985). Evidence of the influence of the university learning experience on the development of these abilities is, at best, ambiguous. While increase in ability has been reported in some domains (Donald & Bateman, 1989), there is a broad range of research to indicate that the traditional undergraduate learning experience does not substantially increase the problem solving ability of students with regard to academic (Keeley, Brown & Kreutzer, 1982; Kolodiy, 1975; Kurfiss, 1988; Larkin & Reif, 1976) or everyday tasks (Perkins, 1985). Even though many faculty acknowledge the shortcomings of student problem solving, explicit attempts to address this issue in the university classroom are few (Dunkin, 1986; McKeachie, Pintrich, Lin & Smith, 1986).

These findings constitute a serious problem in university level teaching. The development of effective problem solving strategies, while important in itself, is also essential to concept acquisition (Tennyson & Cocchiarella, 1986) and to the development of competence in a domain (Glaser, 1987; Rohwer & Thomas, 1989). Competence in a domain is characterized as requiring both highly structured content knowledge and knowledge of effective means to acquire, retrieve and manipulate that content knowledge (Rohwer & Thomas, 1989). In this larger learning context, the discrepancy between faculty expectations and student performance in the area of reasoning and problem

solving (Arons, 1979; Donald & Bateman, 1989) raises serious questions about what ought to be learned and taught in university level courses if competence in a domain is to be developed. Perkins and Simmons (1988) have characterized the level of understanding necessary for competence in a domain as having four frames: content, problem solving, epistemic and inquiry. The content frame consists of domain-specific substantive knowledge. The problem-solving frame includes specific and general problem solving strategies and knowledge associated with their use. The epistemic frame is characterized as knowledge of the criteria which guide valid induction and the evaluation of evidence and theory in a domain. Lastly, the inquiry frame consists of the knowledge required to criticize, elaborate or challenge domain knowledge. In their examination of the factors that contribute to misunderstandings in several domains, Perkins and Simons (1988) found that all four forms of domain knowledge must be addressed if competence is to be developed.

Similarly, but from a more pragmatic perspective, Rohwer and Thomas (1989) undertook a comparative analysis of novice and expert performance to determine the kinds of knowledge which should be pursued in academic courses. They identified three major areas of instruction: facilitating the structuring of content knowledge in terms of higher order principles; integrating with these structures a knowledge of how to solve problems and the conditions under which content and process knowledge apply; and developing the planning and monitoring skills necessary to orchestrate effective learning and problem solving. From both theoretical and pragmatic perspectives, the requirements

for competent performance in a domain place the development of problem solving strategies squarely in the context of academic course instruction.

In contrast, the university undergraduate learning environment, as described in Dunkin's (1986) review of the literature on university teaching, generally provides neither the opportunities nor the explicit instructional support for the development of this kind of competence in a domain. Although the typology of the kinds of tasks required in undergraduate courses varies to some degree by domain (Barnes, 1980; Kyle, Pennick & Shymansky, 1980), learning tasks are generally characterized by lower level cognitive operations and convergent thinking. Students are more frequently called on to recall and comprehend information or perform familiar applications of knowledge than they are to analyze, synthesize or grapple with novel problems (Dunkin, 1986). When cognitive tasks do have the potential to facilitate the development of problem solving strategies, the emphasis is often on outcome and not process (Phye, 1986). Even though process knowledge is implicit in many of the tasks undertaken, it is the information in isolation which many students perceive (Norman, Gentner & Stevens, 1976; Mevarech & Werner, 1985). The result is poor concept learning (Tennyson & Cocchiarella, 1986) and failure to acquire problem solving strategies (Arons, 1979).

These contrasts between instructional theory and practice suggest that, in order to facilitate the development of problem solving strategies students must firstly, be more frequently called on to perform tasks which require higher level cognitive processes such as analysis, synthesis and evaluation (Bloom, 1971). Secondly, the problem solving strategies implicit in these tasks must be made explicit to the student (Glaser, 1987;

McKeachie et al., 1986). This demand for explicitness is shared by a number of effective teaching strategies for developing problem solving ability (Nickerson et al., 1985). The essential components of these effective teaching strategies are: (1) to clearly articulate the strategy to be learned; (2) to provide students with opportunities to practice the strategy and discuss its utility; (3) to provide students with feedback on their process as well as their product (McKeachie, 1988). Two inherent assumptions in these components are that there are strategies which are clear candidates for instruction and that they can be articulated at a level of detail that is meaningful to students. It is in these fundamental assumptions that difficulty arises. What are the strategies we wish our students to acquire? What strategies are most useful in student problem solving? Which expert strategies are most often lacking in student performance and could be most effectively taught? The answers to these questions are essential to the development of effective problem solving strategies in the context of academic courses and constitute the general problem explored in the present study.

### **What is a Strategy?**

The first challenge in further articulating this research question is to clarify the definition of the term strategy. Even within the problem solving context, "strategy" exists in multiple guises, ranging from narrow to broad interpretations. Greeno and Simon (1988) include only very general and complex procedures such as means-end analysis or sub-goaling in their conceptualization. Gick (1986) equates strategy and

heuristic. Gagne and Beard (1978) define strategies as executive control processes. In response to the variable and often poorly defined use of the term "strategy", Chi (1987), Garner (1988) and Pressley and his colleagues (Pressley, Goodchild, Fleet, Zajchowski & Evans, 1989) have each made efforts to define criteria which characterize a strategy. Common elements in these sets of criteria include: (1) strategies are sequences of activity rather than a single event; (2) strategies are goal directed; and (3) strategy use is largely under conscious control. While the definition of strategy proposed by Alexander and Judy (1988) is not explicitly based on these three criteria, their definition of strategy is consistent with them. Alexander and Judy (1988) define strategies as: "goal directed procedures that are planfully or intentionally evoked either prior to, during or after the performance of a task" which "can exist in varying degrees of generality or separation from specific domains" (p. 376). Pressley et al. (1989) have further contributed to the definition of strategy by specifying degrees of generality in which strategies can operate. They differentiate between **task specific strategies** (strategies used in a particular situation, in a particular domain such as mnemonics or mathematical formulae); **goal limited strategies** (strategies tailored to specific goals such as problem solving or writing which may cross domains); and **general strategies** (strategies such as monitoring, planning and evaluation which coordinate specific strategies in many different contexts). Strategies at each level in this taxonomy have associated with them knowledge which includes how and when they can be used, their utility and degree of difficulty. This associated knowledge is essential to effective strategy use (Pressley et al., 1989). The broad definition of strategy proposed by Alexander and Judy (1988), and elaborated by

Pressley et al. (1989), meets the three criteria characterizing strategies and is appropriate to a wide range of strategy research; it was therefore selected for the present study.

### **Executive Control Strategies**

The hierarchy of generality proposed by Pressley et al. (1989), is useful both in the conceptualization of strategies and in designing research on strategy knowledge and use. With a hierarchy of generality (Pressley et al., 1989), it is possible to establish a correspondence between the level of strategy and the level of analysis. In the present study, the level of analysis chosen was the general strategy level: those strategies which may be used in many different contexts to monitor, direct or evaluate cognitive processing. This level of strategy use corresponds to the executive control strategies described in information processing theory and also falls within the domain of metacognitive strategies. Because the present study was conducted within the context of information processing theory (Chapter II), the general strategies of monitoring, directing and evaluating problem solving will be referred to as executive control (EC) strategies from this point on. Following the definition of strategy proposed by Alexander and Judy (1988), EC strategies are defined as goal directed procedures that are planfully or intentionally evoked prior to, during or following the performance of a cognitive task for the purpose of monitoring, directing or evaluating the performance of that task.

For a number of reasons, EC strategies may be among the strongest candidates for instruction at the university level. In the context of problem solving, EC strategies have

been identified as an aspect of human information processing which has substantial potential for development (Perkins, 1986; Sternberg, 1985). The effective monitoring and management of the problem solving process characterizes expert performance in many domains, but is not typical in novices (Andre, 1986; Chi & Glaser, 1988; Clancy, 1988). Experts also use these strategies to facilitate problem solving when working outside of their areas of expertise (Clement, 1982). Successful students were found to more frequently reflect on, monitor, and consciously direct their problem solving process (Champagne, Kolpher & Anderson, 1980; Gay, 1986; Smith & Good, 1984). Beyond empowering the effective use of knowledge, EC strategies also facilitate the acquisition of more specific strategies and are essential to the application of these strategies in new situations (Pressley et al., 1989; Borkowski et al., 1986; Simon, 1980), and thus, could be considered a prerequisite to the acquisition of other levels of strategies. Furthermore, EC strategies can be learned (Borkowski, 1985; Duell, 1986) and successful acquisition and maintenance of these strategies increases with the experience of the learner (Brown, 1978; Kail & Hagen, 1977; Pressley et al., 1984).

Although the use of EC strategies by university students is not extensively researched, there is evidence to support further research in this area. Generally speaking, many difficulties in thinking are due to inadequate monitoring and self-regulation (Baron, 1985). Even "good students" often fail to monitor and make adjustments in their thinking (Garner, 1987; Markman, 1981). This general phenomenon has been evidenced in the problem solving performance of university students (e.g. Bloom & Broder, 1950; Derry, 1989; Derry & Kellis, 1986; Schoenfeld, 1983; 1985; 1987; Smith & Good, 1984).

Furthermore, EC strategies have been observed to be particularly important in the problem solving of novices (e.g. Owen & Sweller, 1985; Voss, Greene, Post & Penner, 1983). The limited amount of research on EC strategies in problem solving at the university level, together with the seeming importance of strategies for monitoring, directing and evaluating the problem solving process, bring focus to the present research problem. These findings suggest that one approach to the rather diffuse issue of facilitating the problem solving abilities of university students may be to explicitly address the development of EC strategies in the context of domain-based problem solving typical at the university level.

In order to develop such an instructional strategy, Glaser (1976) specifies three essential design components: determine the knowledge which constitutes competence in a domain; determine the knowledge and abilities of the learners; and design a sequence of instruction which will develop the learners' competence. In the context of university teaching, it is necessary to enter this instructional design process by exploring the EC strategy knowledge used by professors and students. It is essential to effective strategy instruction that the description of EC strategy knowledge in both groups be as detailed as possible (Heller & Reif, 1984). When this knowledge is articulated, we can begin to answer questions about where the gaps between professors' and students' EC strategy knowledge lie and which EC strategies may be most profitably taught in the context of academic courses.

## The Research Problem

The research literature suggests that EC strategy knowledge is one particular form of strategy knowledge which may be profitably developed in the university classroom. The implementation of such instruction requires the articulation of the knowledge characterizing competent strategy use and the level of strategy knowledge in university level learners. **Therefore, the present study was designed to explore the executive control strategies used by university professors and students and to make explicit the knowledge that is implicit in their strategy use.** Such knowledge could provide a basis from which to improve the effectiveness of instruction at the university level.

In the design process, coherence was sought among the research objective, the conceptual framework and the methodology. A first step in achieving that coherence was to situate the study within an information processing paradigm, and in particular, a cognitive science framework. Cognitive science is a multidisciplinary domain of inquiry directed at understanding intelligent systems and the wide range of mental phenomena which constitute intelligent behaviour (Stillings, et al., 1987). The focus is on looking deeply into behaviour to determine the structures and processes which underlie intelligent behaviour (Kintsch, Miller & Polson, 1984). This focus on underlying process was required to address the present research questions. Within the cognitive science approach, no single theory is prescribed but rather, it is required that the conceptual framework and methodology be compatible and well suited to the research objectives

(Miller, Polson & Kintsch, 1984). The opportunity to select a methodology particularly suited to the research objective, together with the potential for fine grained analysis of the complex problems typical of university learning, were critical to the choice of a cognitive science approach.

The conceptual framework and methodology through which the EC strategy knowledge of professors and students was investigated are elaborated in the chapters which follow. In chapter two, a focused review of the literature is presented. This review concludes with an articulation of the specific research questions pursued. The methodology is described in chapter three, together with a critical review of the relevant literature. An interpretation of the results is presented in chapter four and a discussion of these results follows in chapter five.

## **CHAPTER 2**

### **A FOCUSED REVIEW OF THE LITERATURE**

The study of executive control (EC) strategy knowledge exercised by university professors and students has been identified as a line of research which could make an important contribution to the development of problem solving skills in university classrooms. Such a line of research requires a theoretical framework which has the power, firstly, to conceptualize the nature of EC strategy knowledge and, secondly, to determine an appropriate methodology through which this kind of knowledge can be accessed. The determination of a theoretical framework which can support both the conceptual and methodological aspects of research demands a critical examination of the literature. Consequently, the literature review presented is critical, rather than exhaustive, in nature.

The critical review of the literature has been focused on several themes. The first is the characterization of information processing theory which provides the global framework in which this research has been conducted. A second major theme is the evolving conceptualization of the phenomenon of human problem solving. Based on recent developments in research literature on problem solving, the characterization of the problem solving process is shifting from a purely cognitive phenomenon towards one involving a dynamic interaction among the solver's cognitive resources, personal beliefs and the task (e.g. Schoenfeld, 1983). In this dynamic representation, the role of EC strategies in problem solving is emphasized. This shift in the conceptualization of the problem solving process also establishes a correspondence between problem solving and

metacognition, which has traditionally emphasized the interaction of person, task and strategy variables in cognitive processing (e.g. Brown, 1978; Flavell, 1979). A third theme emerges from this correspondence as relevant parts of the metacognition literature have been incorporated in the conceptual framework of the present study to elaborate the nature of EC strategy knowledge. As a fourth theme, the existing research literature on the use of EC strategy knowledge by professors and students in the course of problem solving is reviewed. The purpose of assuming a critical orientation in reviewing this literature has been to explore how the elements of the conceptual framework provide a coherent and productive perspective from which the knowledge enabling EC strategy use can be better understood and researched in an educational context. The chapter closes with a statement of the specific research objectives for the present study.

### **Information Processing Theory**

The overarching structure of the conceptual framework is provided by information processing theory. Information processing theory is an approach to the study of cognitive activity which focuses on the structures and processes underlying knowledge acquisition and use (Anderson, 1985; Garner, 1988). The articulation of information processing theory developed from a computer metaphor (Broadbent, 1958; Neisser, 1967) which is reflected in its inherent assumptions: (1) that conscious and unconscious behaviour can be described as events consisting of information which is operated on to produce an outcome; (2) that complex events can be decomposed into component processes and

knowledge states; (3) that these components can be temporally ordered to produce a model of the dynamic flow of process (Palmer & Kimchi, 1986). It is primarily in the capacity to decompose covert behaviours and model complex processes and structures that information processing theory exceeds the potential of behaviorism [which did not acknowledge internal representations and cognitive states] or Gestalt theory [which was characterized by phenomena such as incubation and sudden restructuring which could not be decomposed] to understand and articulate process (Dellarosa, 1988). Because of its capacity to articulate process, it is the conceptual framework most widely used by cognitive scientists to understand cognitive processes. Information processing theory provides a theoretical context which supports both the articulation of EC strategy knowledge at a level of analysis useful to instruction and the methodology to access this knowledge.

### The Human Information Processing System

Fundamental to understanding human problem solving behaviour is an understanding of the structures which enable cognitive activity. One framework in which these structures are accounted for is information processing theory. Within information processing theory, the human information processing system consists of a set of structures and functions which enable the input, active processing and storage of information (Estes, 1982; Klatsky, 1980). The structures and functions proposed within information processing theory to account for human cognitive activity can be summarized as follows (Anderson, 1985; Frederiksen, 1984; Estes, 1982; Klatsky, 1980; Newell & Simon,

1972). The primary components of the system are: sensory register, short term memory, long term memory and executive control processes. A high frequency of auditory and visual stimuli are perceived through a huge capacity **sensory register**. Stimuli in this register are short lived and must be attended to in order to be processed further. **Short term memory (STM)** functions (1) to temporarily retain information from perception and long term memory and (2) to maintain information in an active state for processing. It is within STM that the function of working memory or conscious thinking takes place. The capacity of STM is limited to approximately seven units of information (Miller, 1956), but that capacity can be increased by grouping information to form single "chunks" (Newell & Simon, 1972) rather than separate units. STM has only temporary storage capacity and to be retained, information must be constantly rehearsed in STM (Baddley, 1976) or stored in long term memory. The limited capacity and retention span of STM constitute a major defining constraint of the human information processing system.

A large capacity **long term memory (LTM)** is associated with the long term storage and retrieval of information. Information can exist as episodic memory in which specific experiences are stored in spatio-temporal contexts or as semantic memory, in which information about things and processes is stored as concepts and relationships (Tulving, 1972). In either case, the organization and integration of units of information is critical to effective utilization of LTM (Estes, 1982).

The function and coordination of these three components is controlled by **executive control processes** which operate at various levels of consciousness to monitor, direct and evaluate the functioning of information processing system (Sternberg, 1985).

For example, EC processes determine what processes are attended to and for how long; which information will be stored and retrieved; how available resources can be coordinated; and the role of feedback in processing (Anderson, 1985; Estes, 1982; Newell & Simon, 1972; Sternberg, 1985). In well-learned or familiar situations, the EC process can be unconscious and requires minimal STM capacity. In novel situations, performance can be enhanced by directing attention to conscious control of the system (Estes, 1982; Sternberg, 1985). This "freedom of programmability" has been identified by Newell (1973) as an essential and unique aspect of the highly adaptive human information processing system. Under conditions of conscious control, the human information processing system can be intentionally monitored and directed and its output evaluated by implementing selected EC processes (Sternberg, 1985). These selected EC processes which can be intentionally evoked constitute executive control strategies. This component of information processing has been identified as a fundamental source of individual and developmental differences (Baron, 1978; Perkins, 1986; Sternberg, 1985). Furthermore, the development of EC strategies is an aspect of the human information processing system with potential for development (Perkins, 1986).

Despite their importance, the EC aspects of human information processing have not been widely researched. Early research in the information processing paradigm emphasized the nature and structure of the architectural system which enabled processing (Anderson, 1987). With this knowledge in place, contemporary models of thinking (e.g. Baron, 1985; Sternberg, 1985) place a greater emphasis on the function of the human information processing system, and in particular, on the regulation and coordination of

processing (Anderson, 1987; Pressley, Symons, Snyder & Cariglia-Bull, 1985). In the modern information processing context, the role of EC strategies is an important and necessary component of information processing research. Therefore, the potential to consciously control the information processing system during problem solving through EC strategies is the aspect of the human information processing system that is of most interest in the present study.

#### Problem Solving in an Information Processing Context

In the context of information processing, the problem solving process is characterized as a search for a solution carried out within a problem space (Newell & Simon, 1972). When presented with a problem - the task environment - the problem solver constructs a problem space which represents the initial state at which problem solving begins, the desired goal state, possible actions to be taken (operators) and conditions which restrict the choice of relevant knowledge and actions (Holyoak, 1990). Problem solving is the process of moving from one knowledge state to the next through the action of a sequence of operators to achieve the desired goal (Holyoak, 1990; Newell & Simon, 1972; Simon, 1978; Voss, 1991).

While the information processing model of human problem solving does allow for the detailed documentation of the problem solving process, it represents a strong computational model of how the human information processing system functions. It was derived from early research in artificial intelligence which was directed at developing efficient models of human thinking on which to base computer programs (Dellarosa,

1988), and depicts human problem solving as a series of objective, rational means to pre-specified ends (Lave, 1988). From an artificial intelligence research perspective, the human information processing system was considered in parallel to inert computer hardware, because it was the rational component of human information processing which was being modelled. When the power of information processing theory was focused on a broader understanding of human thinking for its own sake, it became clear that human problem solving was a complex system which includes substantive and strategic knowledge, motivation, belief systems, and social interaction (Ceci, 1989; Garner & Alexander, 1989; Heppner & Krauskopf, 1987; Norman, 1980; Pressley et al., 1985; Schoenfeld, 1983; Smith, 1991). It is this broader conceptualization which is utilized in the present study.

### **The Evolving Conceptualization of Human Problem Solving**

Within the information processing framework, the notions of "problem" and "problem solving" have been quite broadly defined. Within these broad definitions, the meanings originally associated with these terms have been elaborated and modified, particularly in the last decade (Greeno & Simon, 1988). These developments are at the heart of the theoretical framework which guides the conceptualization of the present study and therefore, the literature tracing their evolution is outlined here.

### The Nature of Ill-structured Problems

Although the definition of the term "problem" continues to be discussed in the literature (e.g. Agre, 1982; Perkins, 1990; Smith, 1991), the broad definition consistently used by information processing theorists is rooted in Duncker's (1945) characterization: " A problem arises when a living creature has a goal but does not know how the goal is to be reached." (p. 1). In information processing terms, this definition was translated into a situation where there is a given state, a goal state, and obstacles that block movement from the given to the goal state (Newell & Simon, 1972). In both characterizations, the absence of a clear solution path is critical to the definition of a true problem situation. The breadth of this definition encompasses a broad spectrum of situations and consequently, this immense domain has been divided on a number of dimensions. Two dimensions of problems that are useful to explore in the present research context are semantic richness (Bhaskar & Simon, 1977) and degree of problem definition (Reitman, 1965), which Simon (1973) refers to as degree of structure. Although often represented as dichotomies, each of these dimensions exists on a continuum (Voss & Post, 1988).

On the semantic richness continuum, semantically rich problems are those which demand a large amount of domain-specific prior knowledge for their solution. This demand is typical in university level problem solving, where students are expected to bring their own knowledge to bear in problem situations (Bhaskar & Simon, 1977). On the opposite end of this continuum are semantically impoverished problems such as

puzzles (e.g. anagrams) which do not demand substantive knowledge in a domain to be executed successfully.

Within this classification, problems may also vary on a second dimension: their degree of definition or structure. This dimension is somewhat more problematic to characterize, since there are two descriptors involved. Although Sternberg (1989) distinguishes between structure as a function of available solution paths and definition as a function of goals and information, other researchers (Greeno & Simon, 1988; Perkins, 1990; Voss & Post, 1988; Yussen, 1985) use structure and definition in the same sense to connote both process and information. The descriptor of choice seems to be currently shifting to the use of structure but, because "defined" has been widely used in the past and "structured" is just now attaining common usage, the two terms will be considered interchangeable in this review.

The extremes of the original degree of definition continuum were represented by Reitman (1965) as well-defined and ill-defined problems. Well-defined problems have clearly stated initial states and goals, involve a delimited solution path and have a single, correct outcome (Frederiksen, 1984). In contrast, the attributes of an ill-defined problem are:

- (1) the initial state or goal may not be clearly stated, leaving unspecified parameters that must be specified, based on the solver's knowledge (Reitman, 1965). When a problem is perceived to be ill-defined, a substantial part of the solving process is devoted to specifying parameters and selecting relevant information to define the problem representation

(Voss, 1989), a process which often entails the restructuring of the task (Holyoak, 1990, Perkins, 1990). In information processing terms, Simon (1973) refers to this process as closing the problem space.

- (2) the solution steps are not delimited and different paths may be taken to produce a solution (Frederiksen, 1984).
- (3) there will be no single, correct solution (Simon, 1973) and problem solving behaviour will be more variable (Voss, 1989) because variable representations of knowledge and sequences of processing will be evoked.
- (4) the degree of definition of a specific problem is relative. Previous experience in a similar situation, the representation constructed, or later stages in the solving process may render a problem designed to be ill-defined to be experienced as well-defined (Mayer, 1988; Reitman, 1965).

Most problems in human experience are ill-structured (Reitman, 1965; Simon, 1973), but due to their complexity, they have been less frequently studied. The solving of ill-structured problems stretches the constraints of the characterization of problem solving proposed by Newell and Simon (1972) because ill-structured problems have the potential to elicit different and more variable aspects of knowledge relevant to problem solving than well-structured problems (Voss & Post, 1988). The demands for extensive problem representation, greater emphasis on planning, and a greater demand for parallel processing in the solution of ill-structured problems (Holyoak, 1990; Voss, 1989) are expanding our understanding of the problem solving process. As the conceptualization of problem solving matures, it is in turn, growing to accommodate the study of ill-structured

problems. Problems which can be characterized as both semantically rich and ill-structured (ill-defined) are of interest in the present study because of their potential to elicit a broad range of problem solving strategy knowledge; their relevance in both a general and an academic context; and the relative paucity of research in this area.

### The Pressures for a Changing Conceptualization

The shift from a cognitive conceptualization of problem solving to one characterized by the interaction of strategic and substantive knowledge, motivations, belief systems and social interaction has been driven, in large part, by two major developments in problem solving research. The first is the diversification of tasks on which problem solving is studied. The second is the growing evidence for the role of contextual variables in the problem solving process. Each of these developments provide empirical support for the conceptualization of problem solving as a dynamic and interactive process.

### Task selection

The evolution of our understanding of the problem solving process has been influenced by the progression in the kinds of tasks on which problem solving has been studied. Up to the 1970's, well-structured and semantically impoverished, puzzle-type problems were the primary experimental tasks (Bhaskar & Simon, 1977). Research commonly involved puzzles such as the Tower of Hanoi (e.g. Hayes & Simon, 1977), anagrams (e.g. Mayzner, Tresselt & Helbock, 1964), cryptograms (e.g. Newell &

Simon, 1972) or the missionary and cannibals problem (e.g. Simon & Reed, 1976).

Firstly, the selection of these tasks reflected the nature of the questions raised early in the development of problem solving theory which focused on the structures and fundamental processing of the human information processing system (Anderson, 1987; Kintsch, Miller & Polson, 1984). Secondly, this research was constrained by the conventions of psychological research which stressed the importance of controlling variables (Anderson, 1987; Kintsch et al., 1984; Reitman, 1965). Consequently, tasks and the settings in which they were conducted were simplified. Although this research was valuable in characterizing the structures and processes underlying human information processing, the well-structured tasks presented were such as to constrain the problem solving processes across individuals. These tasks offered very few strategy options and common process strategies emerged, resulting in a power-based approach to explaining the problem solving process: it appeared that problem solving ability depended on strong problem solving strategies (Glaser & Chi, 1988; Perkins & Solomon, 1989). When the tasks were expanded to include semantically rich (e.g. physics problems in Larkin, McDermott, Simon & Simon, 1980) and less structured problems (e.g. political policy problems in Voss et al., 1983), problem solving behaviour was less constrained by the context of the problem and richer data matrices [more categories of relevant information and more information within categories] were constructed (Pressley, Heisel, McCormick & Nakamura, 1982). From this data, the important role of knowledge structures in performing knowledge-rich tasks became evident. Problem solvers working from rich knowledge structures and experience in a domain were observed to recognize essential

elements and patterns in problem statements (e.g. Larkin et al., 1980; Simon & Chase, 1973; Schoenfeld & Herrmann, 1982). Experts were also observed to draw on domain-specific strategies and knowledge in solving problems rather than on the general strategies identified in the solution of semantically simple problems utilized in earlier research (e.g. Chi, Hutchingson & Robin, 1989; Elstein, Shulman & Sprafka, 1978; Gay, 1986; Perkins, Schwarz and Simmons, 1991; Simon and Chase, 1973; Voss et al., 1983). The role of domain specific knowledge in problem solving dominated these results and, for a time, the conceptualization of the nature of the problem solving process swung to a knowledge-based process, where problem solving expertise derived from knowledge in a particular domain (Chi, Glaser & Rees, 1982; Glaser, 1984). That swing was moderated somewhat as data accumulated. As a result of research on semantically rich problems, a consensus has developed around the view that the cognitive components of expert problem solving performance involve a complex interaction of knowledge structures and process skills, coordinated by strong self-monitoring and self-regulating skills (Glaser & Chi, 1988).

### Contextual variables

The expanding data matrices also implicated another component in human problem solving and that component is context. Working in the domain of language comprehension, Clark and Carlson (1981) made a major contribution to characterizing the concept of context when they abstracted from the research literature the essential attributes of context. They describe context as information about objects, events, states

and processes that becomes available to individuals over the course of a specific task and which interacts with the performance of that task. Clark and Carlson include beliefs and suppositions in the information which may contribute to context and stress the relativity of contextual information to the person, process and task. Miller (1951) also emphasized the relative nature of context-relevant information in characterizing it as including needs, perception of audience and culture. More recently, Tiberghien (1986) has proposed a more precise definition: "the context can be defined as the whole set of secondary characteristics of a situation or secondary properties of a cognitive or motivational state of an individual which may modify the effect of an effective stimulation (stimulus) or an oriented activity" (p. 109). In this definition, two major sources of contextual information are identified: situational aspects of the setting or task and personal characteristics such as beliefs and attitudes, motivation, emotion and socio-cultural effects. Information from either source can interact with the information processing system to influence what information is perceived (Bower & Cohen, 1972; Thomson, 1986) or retrieved (Bower & Cohen, 1982; Davies, 1986; Tulving & Thomson, 1971; Wyer & Scrull, 1989) and the reasoning process itself (e.g. Cummings, Murray & Martin, 1989; Isen, Means, Patrick & Nowicki, 1982; Linn, Pulos & Gans, 1981; Sternberg, 1983; Turiel, 1989; Voss et al., 1983). Research on context effects suggests that cognitive mediators other than processing ability, knowledge, and executive control components influence problem representation, interpretation and processing (Dweck, 1986). Therefore, the growing conceptualization of problem solving also includes the interaction of elements of context with the human information processing system.

Researchers have probably always recognized that personal and situational contexts influenced the problem solving process. Piaget (in Ginsberg & Opper, 1969) noted that emotion was implicit in intelligent behaviour. More specifically, Piaget (1972) acknowledged that the use of formal operations may be influenced by aptitudes, interests and professional involvements. Newell (1973) emphasized the adaptability of the human information processing system to influences from content and context, which he characterized as "freedom of programmability" (p. 499). Neisser (1963), in criticizing the strict application of the computer metaphor to human thinking, contended that a fundamental characteristic of human thought was "an intimate association with emotions and feelings" (p.195). Simon (1982) acknowledged "important interactions" between affect and thought and observed that psychologists up to that point had attended to "the narrower task of explaining 'cool' thinking" (p. 342). These prominent researchers were not oblivious to the role of context in human information processing, but they were restrained from pursuing these lines of research by conventional research paradigms (Reitman, 1965) which valued the investigation of phenomena in a context-free setting and where context effects were considered as undesirable "noise" (Tiberghien, 1986). Over the last twenty years, the cognitive science paradigm has expanded the arena of research (Kintsch et al., 1984) and contextual variables have begun to enter the formal conceptualization of problem solving process. The importance of this component of human problem solving is strongly argued by Tweney (1991): "Cognition of the sort we are describing occurs in persons, and we neglect the uniqueness of the cognizer at our peril." (p.4). Despite a growing body of research on the role of context effects in

problem solving, contextual variables are frequently ignored or poorly conceptualized in problem solving research (Pintrich, 1988b). For this reason, context effects are given particular attention here.

### Context Effects in Problem Solving

The aspects of the cognizer's context which are most relevant in the present study are those which interact with the problem solving process. In particular, the focus is on the individual's control of the process of solving ill-structured problems. In this situation, the closing of problem parameters is critical to the solving process and the setting of such parameters is largely a product of beliefs, emotions, values and habits (Baron, 1991). Therefore, a number of facets of context relevant to the problem solving process need further elaboration: beliefs about problem solving and one's problem solving ability, motivation, feelings, and social and cultural effects.

From a psychologist's perspective, these aspects of context fall into the affective domain: "a wide range of phenomena, including feeling, emotions, moods, motivations, certain drives and instincts" (Corsini, 1984, p. 32). These affective variables can interact with the information processing system at several levels. Strongly experienced phenomena such as emotion may interrupt processing; other phenomena such as mood or motivation may act more subtly to modify processing or may function to evaluate processing (Simon, 1982). Affective variables also constitute interrelated aspects of the self-system: self-efficacy, self-esteem, locus of control, achievement motivation and attributional beliefs (McCombs, 1986; 1988). Recent research literature emphasizes the

importance of these elements of the self-system in the acquisition and use of strategy knowledge (e.g. Borkowski, Carr, Rellinger & Pressley, 1990; Borkowski et al., in press; Garner & Alexander, 1989; Short & Weissberg-Benchell, 1989). Research on context effects, including the role of the self-system, have contributed to the understanding of the personal and situational context components of the problem solving process. A limited sampling of this literature is presented here to document the important role of this form of knowledge in the problem solving process.

#### Context Effects of Beliefs and Motivation

Of primary importance among contextual variables influencing problem solving are factors associated with the construct of motivation. The boundaries of this construct are very broadly delineated as the factors which contribute to goal-oriented striving (Atkinson, 1964; Beck, 1983). Dweck (1989) characterizes motivation as "cognitive factors (beliefs, inferences) and affective factors that influence children's choice and initiation of tasks, as well as the intensity and persistence with which they pursue them " (p. 87). Borkowski and his colleagues attribute to motivation the capacity to " direct and energize human behaviour", but emphasize that motivation also plays "a more subtle role in determining the actual strength, shape or functioning of cognitive processes" (Borkowski et al., 1990, p. 53). Motivation is a complex phenomenon and is largely the product of one's beliefs (Dweck, 1986; 1989; Nicholls, 1984; 1989). Beliefs may be held about the degree of one's control over outcomes, expectations that selected means will produce outcomes, confidence that those outcomes can be attained, and the value of the

task (Paris & Winograd, 1990; Pintrich, 1988b; Skinner, Chapman & Baltes, 1988).

These beliefs, in turn, influence the problem solving process.

Some of the beliefs discussed in the motivation literature are particularly relevant to problem solving performance. Beliefs about the goals of cognitive activity are fundamental to the understanding of motivation and influence problem solving behaviour. Dweck (1986; 1989; Dweck & Leggett, 1988) has shown that students who consistently believe that the goal of cognitive tasks is mainly to **demonstrate** their competence to themselves or others (performance goals), have different patterns of behaviour than students who consistently believe that the main goal of such activity is to **develop** competence in performing such tasks (learning goals). Similarly, Nicholls (1989) discusses a parallel phenomenon in terms of ego and task involvement. In either case, students who consistently maintain performance (ego involvement) goals are concerned with validating competence; perceive competition in cognitive tasks; avoid or expend low effort in challenges where there is a risk of failure; have rigid (but not necessarily realistic) normative standards of performance; view obstacles as negatives; and attribute failure to lack of ability and success to luck, thereby deriving little satisfaction from either outcome. In contrast, the profile of students who consistently maintain learning (task involvement) goals is characterized by a concern for increasing one's competence; flexible standards of performance relative to self; acceptance of tasks with a risk of failure and high effort and interest in these tasks; view obstacles as learning opportunities and attribute success or failure to effort and strategy use, thereby deriving satisfaction from both outcomes (Dweck, 1989). These patterns of behaviour are not mutually

exclusive and can vary with the task, but have been shown to exist as patterns of beliefs which influence aspects of motivation (Ames & Archer, 1988; Borkowski et al., in press; Dweck, 1989) that are critical to problem solving.

Within these goal-based profiles, other beliefs emerge as important. One's beliefs about the nature of intelligence influence goal choices. Students who believe that intelligence is a fixed ability will favour performance goals, whereas students who have an incremental theory of intelligence believe that ability can be enhanced and will favour learning goals (Dweck, 1986; 1989). Beliefs concerning the reasons for success or failure also influence problem solving behaviour. Students who believe that success and failure are determined by strategies and effort are more likely to accept and seek challenges, persist longer in these tasks (Andrews & Debus, 1978; Fowler & Peterson, 1981); use and transfer strategy knowledge (Kurtz & Borkowski, 1985); and have more positive expectations for performance (Dweck, 1986) than students who attribute success to luck and failure to lack of ability. Positive beliefs about one's overall competence in cognitive tasks enhances performance, persistence (Bandura, 1982; Locke, Zubritsky & Lee, 1982), and the transfer of knowledge and strategies in new situations (Paris, Lipson & Wixson, 1983; Paris, Newman & Jacobs, 1985). Students who believe they have little chance of success on a task will exert little effort in pursuing that task to minimize the damage to self-esteem (Covington, 1985). This is especially true where ego involvement (performance-goal orientation) is high (Pyszczynski & Greenberg, 1983).

Not all task-relevant beliefs emanate from goal or self-beliefs. Perceptions about inherent interest or level of challenge of a task can influence processing, even when self-

beliefs generally favour task engagement. In tasks perceived as interesting or challenging, attention is more focused and more relevant information is retrieved (e.g. Renniger & Wozniak, 1985). Successful solvers have been characterized as invigorated by the challenge (e.g. Smith & Good, 1984). In this respect, Perkins (1990) characterizes the challenge presented by a problem as an essential attribute of a task.

Specific details of the problem situation have also been shown to influence processing. Linn, DeBenedictus and Delucchi (1982) reported that problem solvers reasoned less rigorously in an advertising scenario than in a scientific one. Cummings et al., (1989) found that the social problem solving behaviour of teachers was strongly influenced by situation variables. Similar task content effects have been observed in physics (Linn et al., 1981); the solution of isomorphs of the Tower of Hanoi (Kotovsky, Hayes & Simon, 1985; and in problem interpretation in general (Richard, 1989).

From a broader task perspective, Nicholls (1984) reported that students' beliefs about the primary purpose of education influenced their performance. Students who believe that the primary purpose of education is to produce responsible and knowledgeable citizens tended to fit a learning-goal profile, whereas students who believed the primary purpose was to make them more successful and wealthy tended to fit the performance-goal profile. These examples provide evidence that the beliefs students hold about self and the task at hand contribute in complex and interdependent ways to their motivational patterns and in turn, to their problem solving behaviours. Similar beliefs characterize the independent learner (Borkowski et al., 1989; Paris & Winograd, 1990), the good strategy user (Pressley, Borkowski & Schneider, 1987) and the good

information processor (Pressley, Borkowski & Schneider, 1989), suggesting that their effect on information processing is pervasive.

The literature reported here focuses on the motivation-relevant beliefs of students, and school-aged students in particular. This focus reflects the general emphasis on understanding motivation among school-aged children where the development of aspects of motivation can be observed. There is much less empirical evidence of the role of similar beliefs and goals in the problem solving of university students and experts (McKeachie et al., 1986). Most research on problem solving at the university level has been conducted using an expert-novice approach. The emphasis in this area of research has been to contrast expert strategies and knowledge structures to those of novices in order to understand the nature of expertise. As empirical evidence in this field expanded, the role of affective facets of problem solving began to emerge in the analysis of novice (e.g. Pintrich, 1988b; Schoenfeld, 1983) and expert performance (e.g. Silver & Metzger, 1989), but has not been widely investigated. In reflecting on the accumulated research in this field, Nickerson (1991) concludes that it is essential to cultivate not only processes of effective thinking, but the desire and will to think. Similarly, Posner (1988) suggests that the primary problem in nurturing expertise may not be the development of certain cognitive capabilities exhibited by experts, but the development of the necessary motivation to sustain long periods of study. Consequently, he calls for the assessment of motivation as well as cognitive ability in characterizing the performance of novices and experts. Similarly, researchers in critical thinking call for attention to affective and attitudinal factors including objectivity, fairness and evidence (Ennis, 1987; Paul, 1987).

A more holistic approach is exemplified in a framework proposed by McKeachie and his colleagues (McKeachie et al., 1986) for the study of cognitive processing at the university level. Their framework stresses the importance of including components of motivation in the conceptualization of cognitive processing. Based on these recent developments in expert-novice studies and on evidence from the motivation literature, beliefs relevant to motivation will be included as a component of EC strategy knowledge.

### Context Effects of Feelings

Affective variables other than those contributing to motivation can influence problem solving behaviour. Solvers can come to the problem solving situation in variable affective states such as moods. Alternatively, problem solving can elicit feelings (Mayer, 1986) such as anxiety, pride or shame (Dweck & Leggett, 1988). These affective states have motor-expressive, neurochemical and cognitive components (Mayer, 1986) and hence become part of the problem solving context.

Generally speaking, negative affective states are more likely to be associated with a performance-goal orientation and have greater negative effects on performance, persistence and effort than in a learning-goal situation (Dweck & Leggett, 1988). The effect of emotion on processing is most obvious because, when processing is dominated by emotion, problem solving is often interrupted (Simon, 1982). The effects of less intense affective states may not be immediately evident, but modify the problem solving process in more subtle ways (Mayer, 1986, Simon, 1982). The influence of affective states on cognition is neither straight forward nor simple (Wyer & Scrull, 1989), but

research in this area indicates that, under conditions where positive or negative moods have been induced, adult problem solvers show mood congruent bias. Positive affect has been shown to influence reasoning in a positive direction with regard to judgements in probability estimates (Bower & Cohen, 1982; Johnson & Tversky, 1983); advice in advice-giving scenarios (Mayer & Volanath, 1985); and ratings of one's personal attributes (Derry & Kuiper, 1981) and competence in a domain (Wyer & Scrull, 1989). Negative affect resulted in a consistent negative effect in each of these studies. Positive affect has also been observed to have the more general effect of inducing "impulsive and impressionistic" problem solving styles as opposed to "methodological and effortful" ones (Isen & Hastorf, 1982). The influence of affect is most pronounced when making personal judgements (Pietromonaco & Markus, 1985) and warrants special attention in these situations. More specifically, the affective variable of high test anxiety has been found to have a general negative effect on performance and in a high anxiety situations problem solvers attend less to the task and more to internal events (e.g. Sarason, 1975). Similarly, the feeling of stress reduces the capacity of attention and perception; narrows the range of information searched; reduces the range of alternatives and consequences considered; and increases the likelihood of using oversimplified rules and making errors (Janis, 1982; Mandler, 1982; 1984). Affective variables such as these influence the functioning of the information processing system and contribute to the context in which problem solving takes place. For this reason, the feelings of problem solvers are considered as relevant data in the present study.

### Context Effects of Culture and Social Environment

The problem solving context may also be influenced by cultural differences.

Cultural differences are "persistent beliefs and attitudes that distinguish one group from another" (Hayes, 1990, p. 252). Recent cross-cultural studies have provided evidence that fundamental beliefs about problem solving vary between cultures. In studies comparing Japanese and American views of ability and effort, it has been found that the Japanese place more value on effort as a primary determinant of achievement and less value on ability than Americans (Holloway, 1988). Japanese homes nurture the value of learner control, learning goals and cooperation in learning and problem solving, whereas more emphasis is placed on ability and competition in American homes (e.g. Lee, Ichikawa & Stevenson, 1986). The relative nature of these findings is demonstrated by a study which compared West German and American children's attributional patterns, in which it was found that American parents were more likely to emphasize effort, whereas German parents were equally likely to subscribe to ability and effort in achievement. Furthermore, these values were reflected in the views of their children (Carr, Kurtz, Schneider, Turner & Borkowski, 1988). Findings like these relate directly to research on patterns of personal beliefs influencing motivation, but also identify the larger context effect of culture.

Within cultures, the problem solving process can also be influenced by the social dynamics of a particular task: the people who interact with the solver to provide an audience, set goals, provide input or evaluation (Hayes, 1990). It is this social dynamic which characterizes most educational settings and is an important aspect of academic

problem solving. The effects of this form of context are exemplified by the findings of Voss and his colleagues that problem solvers utilized either "private" or "public" problem solving behaviour, depending on whether they solve problems alone or with others and demonstrated clear reactivity to perceived audience in their problem solving (Voss et al., 1983). Similarly, children in a school setting often opt for a "scientific" mode of thinking, even when they do not believe their answer makes sense, because they believe that kind of thinking is expected in the classroom situation (Tulviste, 1991). Rogoff and Gardner (1984) observed problem solving to be influenced by peer pressure. These few examples are intended to demonstrate that cultural and social elements are constituents of the context in which problem solving takes place. From an educator's perspective, it is essential that our understanding of problem solving performance include a recognition of social and cultural influences.

### Context Effects and The Conceptualization of Problem Solving

This sampling of the literature documenting context effects in human cognition has been presented to underscore the point that human information processing takes place in a personal context created by the cognizer's beliefs, experiences, knowledge and culture. The problem solving path, particularly with ill-structured, semantically rich problems, is modified by the effects of motivation patterns, beliefs about self-concept, attribution patterns, goals and feelings. Pylyshyn (1987) has referred to goals and beliefs which have the ability to consistently alter cognitive processing as "cognitively penetrable". In this sense, these variables go beyond a kind of informational input in

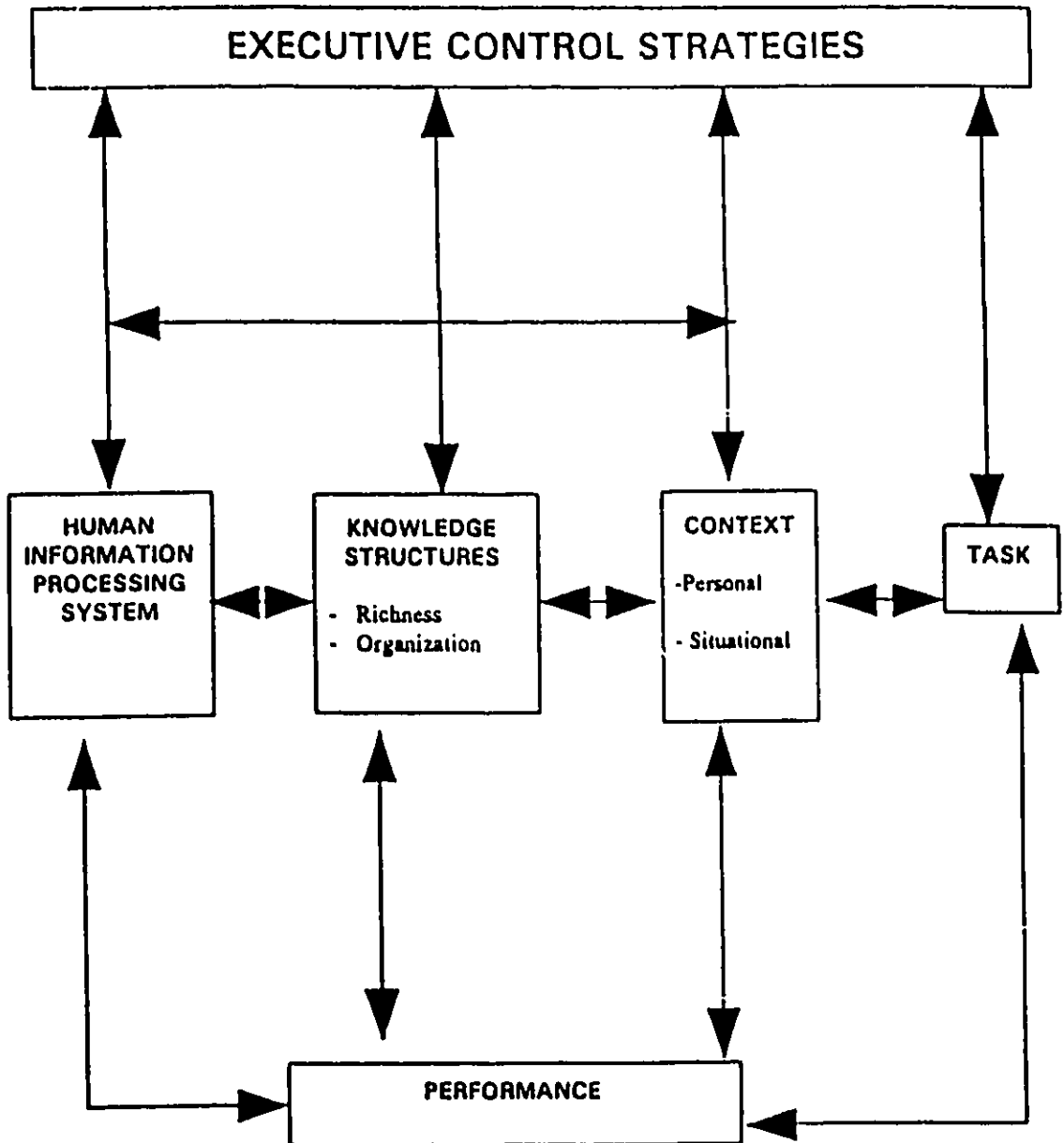
information processing and are capable of interacting with the processing system to influence its functioning (Amy, 1989).

Context effects have been given particular attention in the development of the conceptual framework for the present study because, although they have been acknowledged as mediating variables in the problem solving process, context effects are frequently ignored or poorly conceptualized in problem solving research (McKeachie et al., 1986). The reasons for this situation have been twofold. Firstly, most earlier theories supporting constructs like motivation and affect have not had a cognitive basis and therefore have not been compatible with theory supporting cognition, making it difficult to integrate these components in a single framework (McKeachie et al., 1986). Secondly, and from the perspective of methodology, a more holistic view of problem solving increases the complexity of the research problem, especially in the context of methodologies which favoured context-free designs (Reitman, 1965; Tiberghin, 1986). This methodological constraint hindered the investigation of "contextualized" problem solving (Voss, Perkins & Segal, 1991). The evolution of a common cognitive framework in conceptualizing the various phenomena relevant to problem solving and the development of more diverse methodologies within the cognitive science paradigm have contributed to the conceptualization of the problem solving process depicted in Figure 1: **The Interacting Constraints on Human Problem Solving**. This figure summarizes the fundamental framework from which the present study proceeded.

### Problem Solving: The Current Conceptualization

Within the conceptual framework represented in Figure 1, each component contributes individually to problem solving performance, but also interacts with other components. For instance, the characteristics of the human information processing system set the fundamental processing capacities and limitations, but the functioning of this system is influenced by EC strategies, knowledge structures and contextual variables. Knowledge structures contribute information to the problem solving process, but the use of such structures is mediated by EC strategies, contextual variables and feedback from performance. Context variables are influenced by knowledge structures, the nature of the task and performance feedback. The selection of EC strategies is influenced by the particular task, the internal context of the problem solver, the external context of the physical situation, the existing knowledge structures and the capacities of the human information processing system. In turn, EC strategies influence the functioning of each of the components of the problem solving process.

The primary shift in the conceptual change represented by Figure 1 is typified by the characterizations of problem solving offered by Mayer at two different points in time (1983; 1988). His earlier conceptualization reflects the traditional information processing view of the problem solving process: "a cognitive process in which operators are applied to knowledge in memory, directed at a specific goal" (Mayer, 1983). Writing in 1988, Mayer describes problem solving as a phenomenon which is not purely cognitive, but incorporates intuition and beliefs. This shift is particularly evident in the characterization of problem solving in academic domains. Schoenfeld (1983) describes mathematics



*Figure 1.* A Conceptual Framework: The Interacting Constraints on Human Problem Solving

problem solving as the complex interaction of cognitive resources (facts and procedures), heuristics, control processes and belief systems. Similarly, Silver and Marshall (1990) characterized scientific problem solving as a dynamic interaction of domain knowledge, cognitive and metacognitive strategies, experiences, belief systems and social factors. Voss (1991) emphasizes that, in the social science domain of international relations, cognitive, affective, ideological and institutional constraints are all essential to the decision making process. These examples are representative of recent literature in which the meaning evoked by the term "problem solving" is shifting from a single, general phenomenon (Greeno & Simon, 1988) to a concept of a variable, dynamic and complex interaction between the solver and the task (Heppner & Krauskopf, 1987). As Greeno (1990) has observed, problem solving cannot be considered an autonomous activity, but one which is influenced by the context in which it takes place and the goals to which the problem solving activity is perceived to contribute.

This reconceptualization is especially relevant to the role of EC strategy knowledge in problem solving, and in particular, to EC strategy research in an educational setting. Firstly, it underscores the importance of "freedom of programmability" in the human system (Newell, 1973) and the degree to which information processing is "cognitively penetrable" (Pylyshyn, 1982). The penetration of information processing by contextual effects, which in turn can be intentionally monitored and modified, emphasizes the important role of EC strategies. Inherent in the capacity for flexible programmability in this dynamic context is that effective EC strategies (the intentional monitoring, regulating and evaluation of the problem solving process) are

essential attributes of human problem solving. The exploration of EC strategy knowledge must therefore, take into account the dynamic and interactive nature of the problem solving process. A research design which is founded on the holistic framework proposed here and which focuses on the performance of ill-structured tasks optimizes the spectrum of EC strategy knowledge which may be investigated.

Secondly, this holistic concept of problem solving is also relevant to understanding the problem solving process as it actually occurs. Nowhere is this kind of ecological validity more essential than in the domain of education where the knowledge derived through research is most useful when it is not overwhelmed or invalidated when applied in the complex classroom context. To achieve a greater relevance of problem solving research to classroom practice, Linn (1986) emphasizes the importance of recognizing the interaction of domain-specific knowledge, information processing and context in the problem solving process. The evolving conceptualization of problem solving represented in Figure 1 takes into consideration each of these components of problem solving performance. From an educator's perspective, this conceptualization is both theoretically and functionally sound. Therefore, despite the complexity a holistic approach brings to the research problem, this perspective has been taken to maximize both the range of EC strategy knowledge investigated and the relevance of the results to classroom practice.

### **The Nature of Executive Control Strategy Knowledge**

Within the holistic conceptualization of problem solving which frames this study, EC strategies have been identified as an important component of problem solving behaviour. As characterized in chapter one, EC strategies are goal-directed procedures that are planfully or intentionally evoked prior to, during or following the performance of a cognitive task for the purpose of monitoring, directing or evaluating the performance of the task (cf. Alexander & Judy, 1988). These strategies are evidenced throughout the problem solving process as attention is directed, problems are defined, resources are selected, plans are made and progress is evaluated (Anderson, 1985; Estes, 1982; Sternberg, 1985). Within an educational context, the research focus goes beyond a description of the particular executive control strategies utilized by students and professors and extends to the broader range of knowledge which mediates strategy use. Empirically speaking, research on the instruction of a diverse range of strategies indicates that learning how to execute certain strategies is not adequate for effective strategy use (e.g. Kurtz & Borkowski, 1984; Paris, Lipson & Wixon, 1983; Pressley et al., 1985; 1987; 1989;). Equally important is the conditional knowledge of where and when a particular strategy might be useful (e.g. Larkin, 1979; O'Sullivan & Pressley, 1984; Paris, Newman & McVey, 1982). More recently, there is also increasing evidence for the important role of a more general kind of strategy knowledge in independent and effective strategy use: general beliefs about strategy use, self as problem solver and the task at hand (e.g. Borkowski et al., 1990; Garner & Alexander, 1989; Groteluschen,

Borkowski & Hale, 1990; Kurtz & Borkowski, 1984; Pressley et al., 1985; 1987).

These findings indicate that the knowledge underlying effective strategy use goes beyond knowing what to do. To comprehend the range of knowledge which mediates EC strategy use and to determine the kinds of knowledge to be elicited, it was necessary to conceptualize not only executive control strategies, but the broader construct of executive control strategy knowledge.

### Executive Control Strategy Knowledge as Metacognition

Although the concepts of executive control and metacognition emanate from different research roots, executive control strategies fall within the domain of metacognitive knowledge (Brown, 1987). Metacognition began as a vague concept, as witnessed by Flavell's (1976) characterization: "one's knowledge of cognitive processes or anything related to them" (p.232). One of the subsets of metacognitive knowledge identified by Flavell refers to "the actual monitoring and consequent regulation and orchestration of [cognitive] processes" (1976, p. 232). Schoenfeld (1987) further elaborates this self-regulation aspect of metacognition to include: making sure you understand the problem, planning, monitoring and allocating resources. It is this subset of metacognitive knowledge which corresponds to executive control strategies in the information processing context. Consequently, the knowledge constituting executive control strategy knowledge can be elaborated through the metacognition literature.

Within Flavell's conceptualization, metacognitive activity is the product of a complex interaction of person, strategy and task variables (Flavell, 1979). The

knowledge inherent in these variables includes a personal knowledge of the cognitive apparatus and its functioning, a repertoire of strategy knowledge and a knowledge of types of tasks and their demands (Flavell & Wellman, 1977). Although complex, and criticized as fuzzy (Fischer & Mandl, 1982; Marshall & Morton, 1978), this characterization of metacognition as a multifaceted and interactive set of knowledge (Wellman, 1985) has been borne out in the research literature describing the nature of the problem solving process reviewed above. More specific to strategy use, Flavell's original conceptualization of metacognition as the interaction of strategy, person and task variables is reflected in the characterization of mature strategy use proposed by Pressley and his colleagues (Pressley, et al., 1987). They conclude that mature strategy use is a complex interaction between strategic knowledge, non-strategic (content) knowledge, cognitive style, beliefs and motivation. The literature on metacognition contributes to both the concept of EC strategies and the broader problem solving framework.

As the construct of metacognition has gained credibility through research, so too has the definition of the construct been elaborated. The conceptualization of metacognitive knowledge is a difficult task because it involves tacit and explicit knowledge (Weinert, 1987). Also contributing to this difficulty is that the original broad conceptualizations of metacognition (e.g. Flavell, 1979; Meichenbaum & Asarnow, 1979) have allowed many different interpretations of the phenomenon in framing many different lines of research (Brown, 1987; Kitchener, 1983). A more explicit definition was essential, however, to the collection, analysis and interpretation of data and a number of

researchers have contributed to the definition of that part of metacognitive knowledge relevant to executive control strategy knowledge.

Brown (1978; 1981) has contributed to the clarification process on two fronts. Firstly, she emphasized the monitoring and regulation aspects of metacognition. This emphasis on the function of metacognitive knowledge provided an orientation from which to focus the breadth of knowledge inherent in the concept of metacognition. Secondly, she made the important distinction between two fundamental types of metacognitive knowledge: knowledge of cognition and knowledge regulating cognition. She characterized knowledge of cognition as a static, reportable knowledge of cognitive processing and knowledge regulating cognition as knowledge used to regulate cognitive activity as it takes place which will be more variable between episodes and may not be reportable, particularly in the case of expert performance (Brown, Campione & Day, 1981). In this representation, Brown emphasized that both are legitimate forms of metacognitive knowledge and that the ability to execute metacognitive strategies is a function of their interaction (Brown, 1987). This conceptual foundation is reflected in the modern day consensus that metacognition consists of (1) a knowledge of one's own cognitive processes and (2) the self-management of cognitive resources and the self-monitoring of intellectual performance (Brown, 1987; Nickerson, 1988; Paris & Winograd, 1990). This fundamental characterization is essential in determining what kinds of knowledge are relevant to strategy use and how they might be tapped.

In the development of this consensus, researchers have differed. Kluwe (1987) argues for the restructuring of the notion of knowledge about cognition so that

"knowledge of cognition" becomes part of a large store of declarative (factual) knowledge, and "knowledge regulating cognition" is represented as knowledge enabling: (1) **executive decisions**, which direct the flow of processing by processes such as classifying, checking, planning or predicting; and (2) **executive regulation** of attention, selection, intensity and speed of processing. It is important to note that Kluwe does not dispute the forms of knowledge about cognition portrayed by metacognitive theorists, but how this knowledge is conceptualized in theoretical terms.

Kluwe's division reflects a narrower information processing perspective in which the focus has traditionally been on the control of cognitive processing, rather than a broader knowledge of that control. This narrower perspective is evidenced by the kinds of executive control process research carried out in the information processing paradigm (Yussen, 1985). Two major lines of research involve the description and modelling of executive regulation and executive decisions. A third line of research focuses on how cognitive strategies are acquired and applied. The first two lines of inquiry essentially divide executive control into those aspects which are often automatized with experience, may be very fast and not directly reportable (executive regulation) and those aspects which are deliberate, slow and more amenable to reporting (executive decisions) (Yussen, 1985). Based on the expanding conceptualization of the problem solving process, this focus on the control of process may prove too narrow for the investigation of knowledge relevant to strategy use. Understanding the effective use of executive control strategies demands that more than the process of control be tapped.

The comparison of the metacognition and information processing perspective on executive control strategy knowledge was useful in determining an appropriate level of analysis. On one hand, the traditional information processing approach to investigating EC strategies emphasizes research which focuses on the control of processing through executive decisions or executive regulation. On the other hand, the metacognition conceptualization of EC strategies (self-regulation) is much broader in scope, emphasizing the knowledge which enables the control of processing (Garner, 1987). This broader knowledge focus is coherent with recent literature on the nature of problem solving and strategy instruction and, from an educator's perspective, could be profitably integrated into a conceptual framework underlying EC strategy research.

However, the history of metacognitive research has been plagued by problems of fuzzy definition (Wellman, 1985) and criticism of how such knowledge can be accessed (Brown, 1987; Garner, 1987; Paris & Winograd, 1990). These difficulties have limited the explanatory and prescriptive power of metacognition research (Paris & Winograd, 1990). To overcome these difficulties, Paris and Winograd (1990) have proposed "to limit the construct of metacognition to knowledge about cognitive states and abilities that can be shared among people" and "to expand the scope of metacognition to include affective and motivational aspects of thinking" (p. 21). In limiting metacognition to knowledge which can be shared, Paris and Winograd restrict the meaning of metacognition to include only that knowledge which is in some way verifiable and observable, and in so doing, address persistent methodological concerns. This proposal is consistent with Flavell's (1976) conceptualization of metacognition which was explicitly

based on the assumption of awareness (Fischer & Mandl, 1982). The refinements proposed by Paris and Winograd are also compatible with recent literature on metacognition (Borkowski et al., 1990; Garner & Alexander, 1989) in that this literature incorporates affect and motivation in both the knowledge of cognition and knowledge regulating cognition. This proposal shifts the emphasis in metacognitive research to the self-management of cognitive processing because it is the aspect of executive control most likely to be conscious and therefore accessible (Shiffrin & Schneider, 1977; Yussen, 1985). This emphasis is compatible with an information processing framework and the definition of executive control strategies utilized here.

Whether one agrees that this conceptualization should be applied to all metacognitive research or not, it is particularly apt for describing the conceptualization of executive control strategy knowledge suggested by the review of the literature underpinning the present study. The conceptualization of the problem solving process presented in Figure 1 includes an interaction among executive control strategies, the human information processing system, knowledge structures, a range of context effects and the task. In this dynamic, the importance of executive control strategies is emphasized. The knowledge implicit in EC strategy use is made explicit by research on strategy instruction which indicates that independent strategy use is mediated by a range of strategy knowledge, including declarative knowledge (what), procedural knowledge (how) and conditional knowledge (when and where) (Paris, Lipson & Wixon, 1983). This literature underlines the utility of the broader construct of EC strategy knowledge in education research. The conceptualization of EC strategy knowledge is further elaborated

by the construct of metacognition proposed by Paris and Winograd (1990). Their proposal is helpful in articulating what is meant by executive control strategy knowledge and in setting the broad guidelines for the collection and interpretation of data in the present study. Drawing on these literature sources, executive control strategy knowledge can be defined as that subset of knowledge about cognitive states and abilities related to EC strategies and regulating the execution of EC strategies, which can be shared with others.

#### Specifying Executive Control Strategy Knowledge

The metacognition literature also contributes to a more specific articulation of the kinds of knowledge inherent in executive control strategy knowledge. Based on extensive metamemory research, Pressley, Borkowski and O'Sullivan (1985) developed a model of the kinds of knowledge which constitute metacognitive strategies: Metamemory About Strategies. Pressley and his colleagues proposed that independent and effective strategy use was the product of five interactive and mutually dependent knowledge components. The original model has been revised on the basis of feedback from its application and the incorporation of new perspectives on important components of strategy use ( Borkowski, Johnston & Reid, 1986; Borkowski, Carr & Pressley, 1987; Borkowski et al., 1990; Pressley et al., 1987). The five components of the original model and their subsequent modification are described below.

The first component is a knowledge of how to execute each of the specific strategies in a person's repertoire. The second component is conditional knowledge for

and strategy. The lack of knowledge of when and where to implement the strategy, its expected results, degree of difficulty and track record. This characterization of conditional knowledge is more accurate than the artificial intelligence sense of the term which was used by researchers such as Paris, Lipson and Wilson, (1983) to denote a knowledge of when and where to implement a strategy. Conditional strategy knowledge contributes to strategic change and increases such effective strategy deployment (Barlow et al., 1995). Studies on strategy instruction demonstrate that the conditional component of strategy knowledge influences the spontaneous use and transfer of strategies (e.g., Gillmore & Francis, 1988; Paris et al., 1987). In later versions of the model, these two components of strategy knowledge were integrated to form a single component called specific strategy knowledge (Barlow et al., 1990; Francis et al., 1987).

A third component of the original model was general strategy knowledge, which included the knowledge that strategies required effort and had defined values when properly applied (Francis et al., 1987) and the planning and monitoring cognitive activity a requirement (Barlow et al., 1990). This kind of knowledge approaches a notion of tacit about strategy use (Lipson et al., 1987; Garner & Alexander, 1988). Such tacit knowledge is the probability that a person will search for, modify or apply a strategy (Lipson, 1988) and is the core "strategic" strategy use (Barlow et al., 1995). The component of the model has been extensively developed since its conception. Based on empirical evidence of the importance of the self system in strategy use (Barlow et al., 1992; Barlow et al., 1991) and the growing perspective that strategy use is the product of cognitive motivation and generativity (Barlow et al., 1990). As indicated

in the earlier characterization of the problem solving process, beliefs about one's knowledge, abilities, the situation and the importance of the task are forms of general strategy knowledge which influence strategy use.

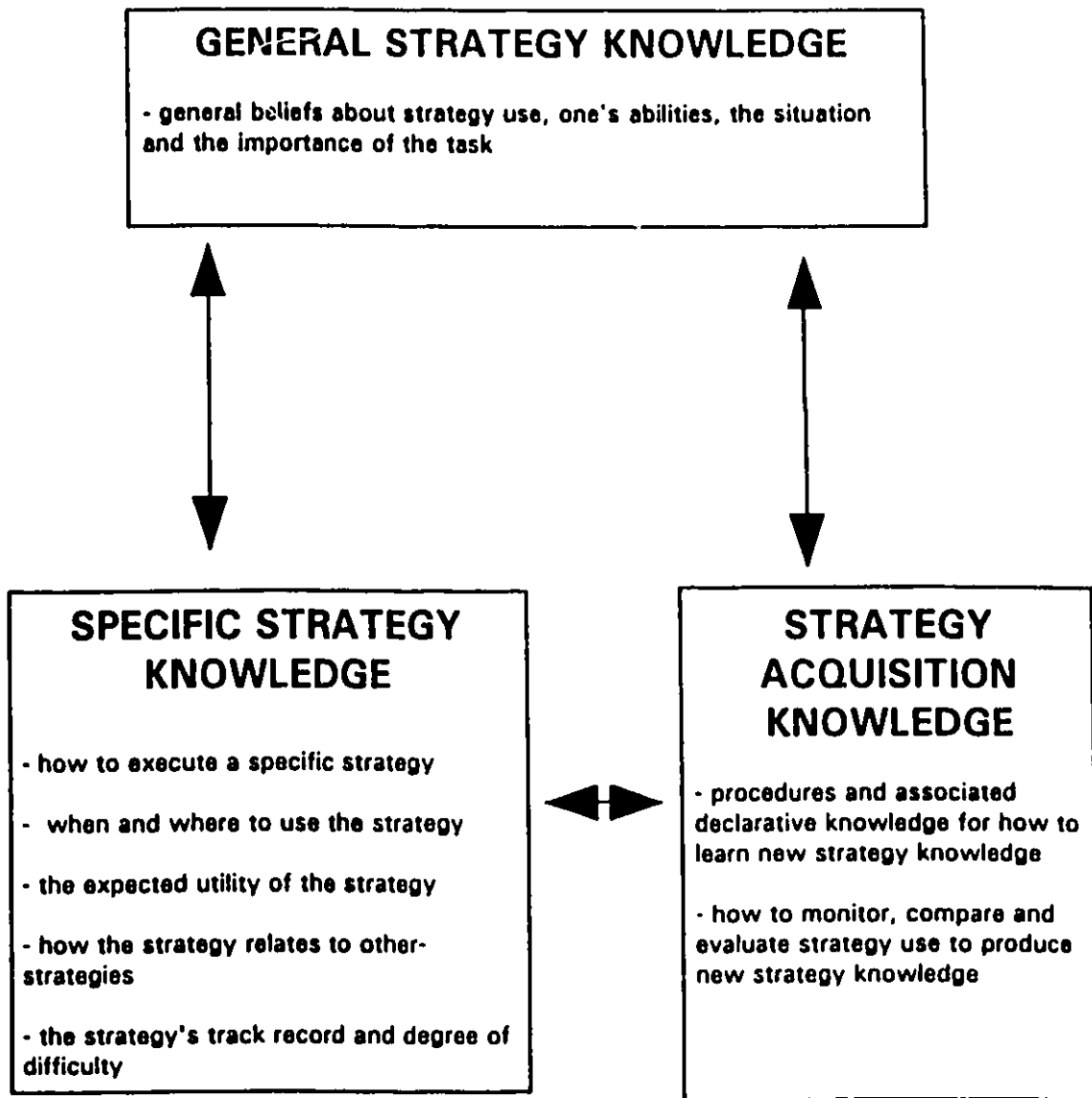
The fourth component of strategy knowledge is strategy acquisition procedures: procedures and associated declarative knowledge for how to learn new strategy knowledge. These strategies operate on other strategies, monitoring and comparing instances of strategy use to allow strategy users to abstract new strategy knowledge from their strategy use, expanding their conditional knowledge and developing new strategies (Borkowski et al., 1990; Chi, 1987). This component of strategy knowledge is essential to the transfer of strategy use to new situations (Borkowski et al., 1986; Brown, 1978; Pressley et al., 1985).

A fifth kind of knowledge implicit in strategy use is relational knowledge: strategic and declarative knowledge about how individual strategies perform similar or related functions. The result of the relational knowledge component is the organization of a classification system for strategy knowledge as experience is acquired. This organization allows strategy users to select the most effective strategy, search for alternative strategies or revise comparative strategy knowledge. In the more recent versions of the model, declarative knowledge of relationships between strategies has been integrated as specific strategy knowledge and the procedures for how to compare and revise strategy knowledge as strategy acquisition procedure knowledge (Borkowski et al., 1990; Pressley et al., 1987).

With the formation of the more inclusive specific strategy knowledge component and the integration of relational strategy knowledge, the revised version of the model (Figure 2: The Components of Strategy Knowledge) consists of three, rather than the original five, major components: specific strategy knowledge, general strategy knowledge and strategy acquisition knowledge. Although developed on the basis of memory strategy research, this model appears to provide a holistic conceptualization of the spectrum of knowledge essential to effective strategy use in general, providing "a heuristic framework which sketches the interacting factors that promote strategic behaviour" (Borkowski et al., 1990, p. 58). This model is coherent with the conceptualization of problem solving on which the present study is founded and it makes explicit essential aspects of strategy knowledge which have been previously under-emphasized in instruction (Symons, Schneider, Cariglia-Bull & Pressley, 1989). Because of its comprehensiveness and its relevance to instruction, this model provides an effective framework for the collection and analysis of data.

### **A Convergence of Themes**

The primary focus in the construction of the conceptual framework was to conceptualize EC strategy knowledge from an educational perspective. The development of this conceptual framework crossed literature on information processing theory, problem solving, contextual variables in problem solving, metacognitive theory and strategy instruction. The construction of the conceptual framework was organized so that



**Figure 2.** The components of strategy knowledge  
(Borkowski et al. 1988; 1990; Pressley et al., 1985; 1987)

each successive sampling of the literature elaborated the conceptualization of EC strategy knowledge achieved in the preceding stage of development. As a final step in building the conceptual framework, this process is reversed to explicitly situate the concept of EC strategy knowledge derived from the literature in the broad framework from which it originated.

The essential aspect of the integration of the literature which has taken place is that the broader knowledge focus on EC strategies characteristic of the metacognition literature has been integrated with research on EC strategy use during problem solving which is embedded in an information processing theory framework. The focus on EC strategy research in an information processing framework is typically on the control of process, rather than on the broader spectrum of knowledge enabling that control. It has been argued that, from the perspective of educational research, the integration of the knowledge focus is essential to gathering the spectrum of knowledge about EC strategy use which is necessary for effective instruction. This argument, and the subsequent integration of literature, draws on three major areas of research to achieve coherence between information processing based research on EC strategies and research on metacognition. The first link between the two approaches is the theoretical parallels between the self-regulation aspects of metacognition and executive control in information processing theory. As demonstrated in the review of the literature, EC in information processing theory bears direct correspondence to self-regulatory components of metacognition. Two other areas of research also bridge information processing theory and metacognition: research on strategy instruction and the literature characterizing the

evolving conceptualization of the problem solving process. Research on strategy instruction, conducted both from information processing and metacognition perspectives, has provided strong evidence that the knowledge essential to effective strategy use includes not only how to use a strategy (control), but a broader spectrum of knowledge which includes conditional strategy knowledge, general beliefs and attitudes about strategy use and knowing how to acquire strategy knowledge. The evolution of our understanding of the problem solving process, which has taken place largely in an information processing context, is characterized by the interaction of the human information processing system, knowledge structures, contextual variables, EC strategies and the task at hand. In both literatures, the emergence of the interaction of person, task and strategy variables characterizes recent research and establishes links to the metacognition literature which has from its inception, maintained that the interactions among person, task and strategy variables are essential to human information processing. This recent convergence of these three areas of research creates opportunities for one research literature to complement the other.

This complementarity has provided a strong conceptual framework from which to explore the knowledge underlying the use of executive control strategies by students and professors. The global information processing theory framework makes possible the detailed analysis and articulation of covert processes and provides the theoretical basis for executive control processes which monitor, direct and evaluate information processing. Those EC processes which may be intentionally evoked are defined as EC strategies. Within this information processing framework, the evolving conceptualization of problem

solving (Figure 1) provides the context from which data is collected and analyzed. This dynamic representation of the problem solving process emphasizes firstly, the importance of EC strategies in problem solving and this component of problem solving behaviour became the focus of the present study. Secondly, this conceptualization emphasizes the interactive nature of the constraints in human problem solving. Consequently, EC strategy knowledge cannot be investigated in isolation and the larger problem solving focus must be maintained during data collection and interpretation. Within this problem solving framework, the conceptualization of EC strategy knowledge was elaborated from the metacognitive literature to include specific strategy knowledge, general strategy knowledge and strategy acquisition knowledge. This elaboration strengthened the educational relevance of the research and its findings and placed the model of strategy knowledge developed by Pressley and his colleagues (Borkowski et al., 1990; Pressley et al., 1985; 1987) in a larger information processing context.

### **Previous EC Strategy Research at the University Level**

To situate the conceptual framework and objectives of the present study of EC strategy knowledge relative to previous research on this topic at the university level, a brief overview of previous research is useful. This overview summarizes the research approaches, the spectrum of strategy knowledge tapped, and some of the major findings of previous investigations. While this research literature identified potential substantive issues for investigation, a critical examination also revealed conceptual and

methodological issues particularly relevant in an educational context. A discussion of these issues and how they influenced the design of the present study concludes this section.

### Previous Research

Although there are exceptions (e.g. Brown, 1987; Quinto & Weener, 1983; Schoenfeld, 1983), the investigation of EC strategy knowledge at the university level is not often an explicit focus of research. There are at least two factors which contribute to this situation. Firstly, the metacognitive literature, which explicitly addresses the investigation of EC strategy knowledge as it is defined here, emanates from developmental psychology roots. Research conducted within a metacognition paradigm is therefore typically based on populations younger in age than university students and professors. Secondly, problem solving at the university level takes place almost exclusively in the context of semantically rich and complex domains. Consequently, information about students' and professors' monitoring, directing and evaluation strategy knowledge is more frequently embedded in the broader study of problem solving in specific domains, than investigated as a separate phenomenon.

Within the domains typical of university level problem solving, research has been conducted primarily in an expert-novice paradigm (Voss, 1989). This research approach typically requires domain experts and novices to perform domain-based tasks. The analysis of these performances yields a characterization of the cognitive structures and processes of novices and experts. These characterizations often include information about

EC strategy knowledge, and particularly knowledge of how, when and where EC strategies are utilized.

Across domains within the expert-novice literature and across research traditions where relevant research has been conducted, patterns of findings regarding students' and professors' EC strategy knowledge are similar. Generally speaking, students have been characterized as less effective users of monitoring, directing and evaluating strategies than experts (e.g. Bransford & Vye, 1989; Schoenfeld, 1985) and less aware of situations in which EC is required (Chi & Glaser, 1988). However, not all students are poor problem solvers, and effective problem solvers, whether students or professors, are characterized by the degree to which they reflect on process: monitoring, directing and evaluating their performance (e.g. Gay, 1986; Smith, 1991; Smith & Good, 1984; Voss et al., 1983).

More specifically, differences in EC strategy use between experts and novices are reflected at various stages in the problem solving process:

(1) Representing the problem. Constructing an effective internal representation of the problem is central to expert problem solving (Simon & Simon, 1978; Voss et al., 1983). Expert problem solvers spend more time on representing a problem (Swanson, O'Connor & Cooney, 1990; Voss et al., 1983), identifying and extracting more relevant information from the problem statement than ineffective solvers (Tweney & Walker, 1990). Experts frequently take a preliminary qualitative approach, first representing the problem in terms of general principles and laws, then in terms of the particular situation (Larkin & Chabay, 1989; Schoenfeld, 1985). Expert problem solvers are more likely to use visual and verbal elaboration of information in the problem statement to content

information given in the problem with prior knowledge (Clement, 1991; Bransford et al., 1989). They frequently restructure the problem to render it solvable (Derry & Kellis, 1987), especially in the case of ill-structured problems (Voss & Post, 1988). In contrast, ineffective problem solvers (frequently novices) are not likely to elaborate problem information or restructure the problem. They persist in verbatim reading of a problem statement (Derry & Kellis, 1986) focusing on literal details in the problem (Chi, Feltovich & Glaser, 1982), rather than "the big picture" (Voss, 1989).

(2) Analysis. Expert problem solvers expend more effort than novices to analyze a problem statement (Schoenfeld, 1985; Schultz & Lochhead, 1991), decomposing problems and identifying sub-problems and their interactions (Bloom & Broder, 1950; Voss et al., 1983). Experts are also more likely to see similarities between problems (Smith, 1988) and utilize analogy more frequently than non-experts (Clement, 1991; Schultz & Lochhead, 1991). In ill-structured problems, experts more frequently see the implications of information given in the problem, add constraints and recognize boundaries inherent in the problem statement than non-experts (Voss et al., 1983).

(3) Planning and Implementation. From a metacognitive perspective, Brown (1987) characterized effective adult planners as: making more global plans; working in a controlled and systematic way; making more use of world knowledge; and demonstrating flexibility in changing the focus of attention. Similarly, the expert-novice literature attributes to expert (but not novice) performance: the construction of a general, qualitative plan before a detailed plan is undertaken (Larkin, 1979b; Voss, 1989); the evaluation of plans; and the monitoring of the implementation of the plan as a solution is

generated (Schoenfeld, 1985). Experts express greater confidence than novices, but more frequently monitor for errors during the implementation phase (Schultz & Lochhead, 1991). In contrast, novices (students) often engage in less planning, fail to evaluate the utility of their plan, or neglect to follow the plan in implementing their solution (Bloom & Broder, 1950; Schoenfeld, 1985).

(4) Evaluation. Evaluation, either by direct examination of process or through the consideration of possible implications, is more likely to be used by solvers with more domain-specific information (Voss et al., 1983). Expert performance is also characterized by a search for possible alternative solutions to a problem (Schultz & Lochhead, 1991), whereas novices tend to present the first solution arrived at and often accept weak solutions without critical assessment (Schoenfeld, 1985; Schultz & Lochhead, 1991; Voss, 1989). In the social sciences, more extensive evidence and argumentation characterize expert solutions relative to the solutions of novices (Voss, 1989).

Collectively, these research findings provide evidence for the general view that effective problem solvers exhibit more effective executive control of the problem solving process and provide a preliminary framework from which the articulation EC strategy knowledge can be initiated.

### A Critique of Existing Literature

From an educator's perspective, a critical analysis of the research literature relevant to EC strategy knowledge at the university level reveals three areas of concern.

Firstly, problem solving research at the university level is dominated by studies conducted in an expert-novice paradigm (Voss, 1989). Secondly, with the focus on expert and novice problem solving, there is a particular paucity of research on problem solvers of intermediate ranges of ability. Thirdly, researchers from both theoretical and instructional perspectives are calling for research in domain-based problem solving. A critique of existing literature based on these three points provides a bridge between the broad conceptual framework underlying the present study and the research objectives at the end of this chapter. For this reason, each of these concerns is further elaborated.

### Expert-novice research

The results of expert-novice research have made it possible to characterize the cognitive structures and processes inherent in novice and expert task performance, and as such, have made important contributions to the development of artificial intelligence and to the acquisition of expertise by human learners (Glaser & Chi, 1988). As with any single approach to research, however, the expert-novice paradigm has limitations. Among these limitations is the fact that, in order to accommodate expert and novice solvers, experimental tasks in conventional expert-novice research have usually consisted of typical problems in a domain (Perkins, Schwartz & Simmons, 1991). Relatively little research has been directed at expert solution of complex problems (Greeno & Simon, 1988) or at how problem solving expertise is applied outside the expert's area of specialization (Clement, 1982; 1991). Peverly (1991) seriously questions whether performance on typical, single-level tasks by experts and novices can be considered to

reflect the same level of problem solving performance. Perkins et al. (1991) point out that while these tasks are typical for experts, and readily evoke domain-specific knowledge and strategies, they are much more likely to represent an atypical challenge for the novice, who has neither the rich knowledge structures nor the problem solving experience of the expert.

This criticism appears to be borne out in the results of research in which atypical problem solving is studied (e.g. Perkins et al., 1991) or where experts are asked to bring their problem solving expertise to bear outside of their usual domain (e.g. Clement, 1982; 1991). In both situations, a broader range of domain-specific and domain-general procedures are observed in expert performance. Of particular relevance to the present study is that the EC strategies of monitoring, directing and evaluating are demonstrated by experts to a much greater extent in novel or unfamiliar situations (Clement, 1982; 1991). The type of task selected influences the problem solving knowledge that is elicited and subsequently characterized as novice or expert.

These observations raise questions about the breadth of problem solving knowledge in conventional expert-novice studies. The focus on expert-novice data analysis is primarily on the content or process knowledge used, and the conditions under which it is evoked. This emphasis reflects the artificial intelligence roots of expert-novice research. While this breadth of knowledge was sufficient for this purpose, it appears not to characterize the full breadth of problem solving knowledge. Firstly, there is the evidence from atypical and unfamiliar problems. Secondly, there is the evidence brought forth in the development of the conceptual framework above, that expertise is not

only a cognitive phenomenon, but the result of the interaction of cognitive, personal, and social components. This broader conceptualization of knowledge relevant to problem solving is essential to developing expertise in a human, rather than a machine context. Such relevant problem solving knowledge has been documented in past research (e.g. Bloom & Broder, 1950; Schoenfeld, 1983; Voss et al., 1983), but is not commonly addressed in expert-novice research. From an educator's point of view, expert-novice research has made important contributions to how we understand and can nurture the development of expertise, but the constraints imposed by the choice of tasks and the breadth of knowledge tapped must be addressed in further research in the educational context.

#### Intermediate levels of expertise

There is another aspect of conventional expert-novice research which merits particular attention when considered in the context of educational research. Expert-novice studies are typically cross-sectional rather than longitudinal in the range of expertise sampled (Voss, 1989). Although a small number of studies have included subjects with intermediate levels of expertise (e.g. Hackling & Lawrence, 1988; Larkin, 1979b), conventional expert-novice research rarely taps intermediate levels of expertise. Consequently, we have come to understand expert performance as it relates to novice performance, and much strategy teaching at the university level has been founded on teaching expert strategies to novices. In recent literature, however, the assumption that the development of expertise proceeds on a direct path from novice to expert is being

The first part of the report deals with the general situation of the country in 1950-1951. It is a very interesting and detailed study of the economic and social conditions of the country at that time. The author has done a great deal of research and has gathered a wealth of material which is presented in a clear and concise manner. The report is well organized and easy to read. It is a valuable contribution to the knowledge of the country's history and development.

The second part of the report deals with the specific details of the country's economy and social structure. It is a very thorough and detailed study of the various aspects of the country's life. The author has done a great deal of research and has gathered a wealth of material which is presented in a clear and concise manner. The report is well organized and easy to read. It is a valuable contribution to the knowledge of the country's history and development.

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### Domain based research

The third major consideration in developing the research objectives for the present study was the call from researchers from various fields for domain based strategy research. From a theoretical perspective Anderson (1987) argues for the domain based investigation of problem solving as a means to move towards an understanding of the general phenomenon of problem solving. Similarly, Smith (1991) views the study of problem solving in individual domains as essential to the development of a unified theory of problem solving.

From a narrower theoretical perspective it has been suggested that domain based research is necessary to determine the degree of domain-specificity of different forms of strategy knowledge (Anderson & Paul, 1998; Paulsen et al., 1999; Sparshoof, 1999). From an instructional perspective the utilization of strategy knowledge from within each domain is fundamental to instruction in those domains (Donald & Gwynne, 1995; Polson, 1989). The selection of which strategies might be useful is often dependent on a rational or non-rational basis without empirical grounding (Laird, Glaser & Van Lehn, 1986). Qualitative and effective strategy instruction hinges on such empirical evidence. The investigation of domain based strategy knowledge would contribute to the development of more instructional materials and to research in the larger theoretical context.

### Modifying The Expert-Novice Approach

An analysis of the research literature on EC strategy knowledge at the university level supports further research in this area. However, this same research literature suggests ways in which new investigations conducted from an educational perspective could profitably differ from previous research. Although the research problem proposed in chapter one focuses on the EC strategy knowledge of professors (experts) and students (novices) in specific domains, it will differ from conventional expert-novice research in ways suggested by a critical review of the literature.

- (1) The breadth of strategy knowledge elicited will include not only the knowledge of how and when to use EC strategies, but how that knowledge is acquired as well as general beliefs about problem solving and EC strategy use. This breadth of knowledge reflects EC strategy knowledge which is relevant from an educational point of view.
  - (2) The students in the study will not be absolute novices, but will have acquired an intermediate level of expertise in their area of specialization. This range of expertise is rarely investigated in expert-novice studies.
  - (3) All participants in the study will be asked to solve real problems from their domain of specialization and a control problem from outside of that domain in an effort to maximize the range of EC strategy knowledge elicited.
- These departures from conventional expert-novice designs are reflected in the research objectives which follow and in the methodology described in chapter three.

## Research Objectives

Based on the foregoing review of the literature, the research objectives of the present study are:

- (1) to explore the executive control strategies and associated strategic knowledge used by professors while solving ill-structured problems within their domain of expertise, and outside of that domain.

The holistic conceptualization of human problem solving which undergirds the present study (Figure 1) emphasizes the important role of effective EC strategies in expert problem solving. The articulation of the EC strategy knowledge used by experts is essential to the development of effective EC strategies at the university level. The elaboration of expert EC strategy knowledge would contribute both to an understanding of the gaps between students' and professors' knowledge and to possible alternatives for explicit instruction. However, in the case of the expert solver, strategy knowledge is often embedded in, and sometimes depends on, specific expert knowledge. Consequently, the articulation of the EC aspect of expert knowledge may be difficult for students and professors to abstract. In addition, the expert's use of executive processes is often internal to the point of automaticity and only becomes explicit when a task is novel and challenging (Luch, 1986; Sarason, 1985). It has been suggested that when experts solve problems outside of their usual domain of expertise, they show strong executive control strategy use which is not dependent on domain specific knowledge (Luch, 1986; 1987). This familiar/unfamiliar domain approach may be useful in eliciting EC

strategy knowledge from experts. This domain comparison is also important to the determination of EC strategy knowledge which is truly "general" strategy knowledge (Sternberg, 1989).

- (2) to explore the EC strategies and associated strategic knowledge used by university students while solving ill-structured problems within a chosen domain of expertise, and outside of that domain.

The exploration of the EC strategy knowledge of students is essential to understanding the nature of EC strategy knowledge and the instructional task in facilitating the development of EC strategies. While gaps in EC strategy knowledge between professors and students may indicate areas of EC strategy knowledge which may be profitably addressed in teaching at the university level, the EC strategy knowledge demonstrated by students is also a potentially rich data source. The EC strategy knowledge of students is likely to be more accessible than that of experts whose EC strategy knowledge has often become tacit or is confounded by experience in the domain (Smith, 1991). It is also possible that effective student problem solvers may utilize EC strategy knowledge more extensively, for different functions or under different conditions than professors. Therefore, the articulation of student EC strategy knowledge may contribute to useful models for the instruction of less expert students as they progress along a continuum of expertise.

- (3) to examine the cross-expertise and cross-domain differences in (a) the EC strategies and (b) the strategic knowledge associated with EC strategies applied by professors and students in the solving of ill-structured problems within their chosen domain of expertise and outside of that domain.**

The purpose of the comparative element of the present study is firstly, to articulate the EC strategy knowledge of professors and students at a level of detail that is useful to the definition and solution of some the teaching and learning problems at the university level. Secondly, the cross-domain and cross-expertise comparison of not only the taxonomy of EC strategies, but the specific instantiations of strategies, their functions, conditions for use and sources of acquisition are essential to a holistic understanding of the phenomenon of executive control strategies.

## CHAPTER 3

### THE METHODOLOGY

The description of the methodology presented in this chapter has been guided by the characteristics of a strong methodology identified by Ericsson and Crutcher (1991). They consider a strong methodology to be one which: (1) ensures the collection of valid and reliable data; (2) is consistent with the theoretical framework and research objectives of the study; (3) defends any anticipated challenges to validity and reliability. This rigorous approach to methodology is especially important when data sources involve verbal reports. A verbal report is a subject's account of his or her own mental processing (Ericsson & Simon, 1984). At a theoretical level, the reliability and validity of these data sources have not gone unchallenged (e.g. Nisbett & Wilson, 1977). On the practical level, there have been legitimate and illegitimate uses of verbal report data (Anderson, 1986). Some research has been criticized for scant descriptions of procedures, type of data collected and inconsistent use of procedures across subjects (Afflerbach & Johnston, 1984; Anderson, 1986; Ericsson & Simon, 1984; Garner, 1988). There is however, growing theoretical and empirical support, developed within an information processing theory framework, for the carefully specified use of verbal reports in cognitive process research (Ericsson & Simon, 1984; Garner, 1988). This juxtaposition of criticism and supporting evidence makes it necessary not only to specify the procedures used in the present study, but to critically review the literature which underlies the valid and reliable use of verbal report data. Consequently, this chapter consists of the rationale underlying the methodology selected and a critical examination of

the literature which prescribes the use of the methodology, as well as a description of how the methodology was used and how the data were prepared for analysis.

### **The Rationale**

The research objectives articulated at the end of chapter two require a methodology which can capture evidence of executive control strategy knowledge. This knowledge is typically complex, used in a covert way and is not readily observable in the products of cognitive activity. The use of product data to determine strategy knowledge is often inaccurate (Siegler, 1989), in part because it requires high levels of inference about covert processing (Cohen 1987; Ericsson & Simon, 1987). The methodological challenge in the present study is to create conditions under which usually covert strategy knowledge is externalized in an observable form with minimal interruption of normal processing. The knowledge to be externalized includes a wide spectrum of executive control strategy knowledge originally proposed by Pressley et al. (1985) and includes : (1) the strategies actually used in problem solving and conditional knowledge associated with their use; (2) knowledge of how strategy knowledge can be acquired; and (3) general beliefs about strategy use. The methodology selected should have the potential to access this whole range of typically covert knowledge, and yield valid and reliable data.

There is no single method which had been shown to access this breadth of strategy knowledge (Kail & Bisanz, 1982). There are, however, related studies in which a two-pronged approach has been used to access firstly, the strategies used in a problem solving

task and secondly, other forms of knowledge associated with strategy use (Haastrup, 1987; Kuipers & Kassirer, 1984; Larkin & Rainard, 1984; Lundeberg, 1987). In the studies cited, the data sources were concurrent verbal protocols complemented with retrospective debriefings conducted immediately following the task. Concurrent verbal protocols (CVP) are verbatim records of a problem solver thinking aloud while solving a problem. Retrospective debriefing (RD) is the problem solver's account of how a problem was solved, reported following the problem solving activity. Kuipers and Kassirer (1984) reported that CVP data provided a record of the strategies implemented during problem solving, whereas RD data provided an opportunity to elaborate strategies and access other forms of strategy knowledge.

In the context of the present research objectives, the complementary use of CVP and RD data in these studies appeared to have two primary advantages. The first was that the CVP/RD methodology provided a more comprehensive account of strategy knowledge than had previously been obtained using CVP alone. In addition to the range and richness of the information gathered, this approach also provided opportunities for CVP data to prompt and validate RD data (Ericsson & Simon, 1984; 1987; Haastrup, 1987) and to use RD data to reduce the degree of inference in the interpretation of CVP data (Grotjahn, 1987; Poulisse, Bongaerts & Kellerman, 1987). Despite these apparent advantages, this dual methodology has appeared only recently in the literature and is not yet widely used. In addition, the use of CVP methodology to tap process knowledge in ill-structured activities has been criticized by Cooper and Holzman (1983) who argue that a process must be defined before CVP can be utilized. This is a narrow interpretation of

CVP methodology, which can be invoked to build and enrich models, as well as test them (Ericsson & Simon, 1984). However, because of the infrequent use of the methodology and the concerns raised by Cooper and Holzman with regard to ill-structured tasks in particular, a pilot study designed to test the methodology was undertaken (Taylor, 1990).

### **The Pilot Study**

The objectives of the pilot study were (1) to determine the potential of CVP and RD data in describing the executive control strategy knowledge of professors and students engaged in solving ill-structured problems; and (2) to explore the type of coding grid which might be useful in the analysis of the resulting data.

In the pilot study, one professor and one student from the domain of biology and one professor and one student from the domain of political science were asked to solve two ill-structured problems while thinking aloud and, immediately following each solution, to discuss with the researcher their solution process. This procedure produced CVP and RD data, respectively. All verbalizations were audio-taped and transcribed verbatim for analysis. Any notes made by the solvers were also retained as data. The analysis of these data focused on the nature of the information relevant to EC strategy knowledge which was present, the kinds of information which characterized CVP and RD data, and the consistency of information across CVP, RD and notes data.

The results of the pilot study strongly supported the use of the dual CVP/RD methodology. These two data sources complemented each other to provide a much more

comprehensive and reliable account of EC strategy knowledge manifested than either data collection method provided when used alone. More specifically, the CVP data provided an account of the strategies which controlled the problem solving process and provided a frame of reference for RD data. The CVP data revealed less evidence of the other forms of strategy knowledge which mediate strategy use. In contrast, the RD data provided more information about the strategy knowledge which mediates strategy use: conditional knowledge, strategy acquisition knowledge and general beliefs and attitudes about strategy use and elaborated the strategy use demonstrated in the CVP data. The results of using two data sources went beyond a simple additive effect. Each data source provided opportunities to elaborate, clarify and verify information available through the other. These two data sources, together with secondary data sources such as notes made by the problem solvers, also provided opportunities for triangulation where data overlapped and thus enhanced the reliability of the findings.

A second aspect of the findings of this pilot study is relevant to the present study. The analysis of verbal report data requires the development of a coding grid. The coding grid developed for the pilot study proved effective in characterizing the executive control strategy knowledge of problem solvers working on ill-structured tasks. The development of this grid is fully elaborated later in this chapter.

### **The Literature Prescribing The Methodology**

Although used extensively in the field of cognitive science over the last twenty years, the collection and analysis of verbal report data related to cognitive processing is not a universally accepted research methodology. At the heart of the debate surrounding the use of verbal report data is the issue of whether, or under what conditions, cognitive processing can be reliably accessed and reported. It is a debate which has spiralled through history as philosophers (e.g. Descartes, 1641/1951; Hobbes, 1656/1839; Howe, 1991; Lyons, 1986; 1991) and psychologists (e.g. Ericsson & Simon, 1980; Nisbett & Wilson, 1977; Titchner, 1910; Watson, 1925) have continued to argue human ability to introspect. While the history of the debate sets the context of scepticism which pervades the modern day perception of verbal data use (Ericsson & Simon, 1984; Anderson, 1986), the focus here is on more recent arguments posed in the framework of information processing theory. Information processing theory may be applied to develop, understand and evaluate methodology as well as conceptual frameworks. This application of information processing theory to the methodological debate, together with mounting empirical evidence, contributes to the clarification and validity of the methodology.

In the modern-day context, the use of verbal data was flatly rejected by Nisbett and Wilson (1977) who claimed that: "There may be little or no introspective access to higher order process" (p. 231). On the basis of their review of the literature, they came to the general conclusion that such data were neither reliable nor veridical. It was their conclusion that only the product of thinking was accessible and that any report of process

was the result of inference from beliefs held about the nature of the thinking process. The sweeping generality of their conclusions has been challenged in more recent research literature (e.g. Ericsson & Simon, 1980; 1984; Smith & Miller, 1978; Steinberg, 1986; White, 1980). Most important among these challenges has been an extensive effort by Ericsson and Simon (1980; 1984) to characterize the reliable use of verbal data. While often portrayed as a rebuttal to Nisbett and Wilson, the findings of Ericsson and Simon may be more accurately characterized as a refinement of the Nisbett and Wilson position. In this refining process, they take great care to specify the constraints under which verbal reports can be reliably collected and analyzed. It is their conclusion that: "verbal reports, elicited with care and interpreted with a full understanding of the circumstances under which they were obtained, are a valuable and thoroughly reliable source of information about cognitive processes" ( Ericsson & Simon, 1980, p.247).

The divergent positions on verbal report data represented by Nesbitt and Wilson (1977) and Ericsson and Simon (1980; 1984) raise important issues which must be clarified where verbal report data are used. Furthermore, the constraints and circumstances which are critical to Ericsson and Simon's proposed procedures for collecting and interpreting verbal report data are not widely understood. Therefore, the literature which advances the resolution of the debate surrounding the use of verbal report data and the specification of the constraints associated with the validity and reliability of verbal report data is reviewed here.

**The Nisbett and Wilson versus Ericsson and Simon Debate**

The challenges to the validity of verbal report data in higher order thinking research raised by Nisbett and Wilson (1977) are serious. Their arguments against the use of verbal report data were based on empirical evidence which appeared to challenge the view that cognitive processes could be reliably accessed and reported. These criticisms must be carefully considered in assessing the credibility of verbal report methodologies.

Although the research presented by Nisbett and Wilson has been criticized for its design (Smith & Miller, 1978; White, 1980) and the statistical analysis underlying some conclusions (White, 1980), the criticisms most relevant to the current discussion are conceptual in nature. A critical examination of the research on report data by Nisbett and Wilson (1977) and Ericsson and Simon (1980; 1984) point to three issues which, when considered closely, resolve many points of difference.

The first issue is the fundamental question of what kinds of process information (if any) are accessible and reportable. Based on information processing theory, Ericsson and Simon (1980; 1984) make the primary assumption that only information currently heeded in short term memory (STM) or which has been previously heeded in STM, fixed in long term memory (LTM) and retrievable from LTM, can be reliably reported. Three practical corollaries of this assumption relevant to the Nisbett and Wilson research are:

- (1) Only conscious processing can be reported (Ericsson & Simon, 1980; 1984; Garner, 1988; Kellogg, 1982; Weilde & Wagner, 1982).

- (2) Not everything attended to will be reported (Cohen, 1987; Ericsson & Simon, 1984; Hayes & Flower, 1983; Weilde & Wagner, 1982).
- (3) Explaining why one did something requires extensive inference and is a different task than describing what one did (Ericsson & Simon, 1984; Garner, 1988; Meichenbaum, Burland, Gruson & Cameron, 1985).

When the Nisbett and Wilson studies are examined, it becomes apparent that the processes they attempted to tap violated the cardinal constraint on reliable verbal reports identified by Ericsson and Simon. Their studies consistently required subjects to report on processes that were unlikely to be conscious (e.g. subliminal perception; awareness of factors which influence problem solving; learning without awareness) or that required explanation (attribution and judgement studies). Nisbett and Wilson also assumed that failure to report reflected failure to access (Smith & Miller, 1978). This is not necessarily true, considering the reporting constraints of limited STM capacity to think and give concurrent reports (Weilde & Wagner, 1982) and incomplete transfer and retrieval from LTM of information previously held in STM (Hayes & Flower, 1983). Neither does it hold that missing information invalidates the information which is reported (Ericsson & Simon, 1980; Hayes & Flower, 1983). The assumption that failure to report corresponds to failure to access is particularly questionable in those Nisbett and Wilson studies in which subjects were not informed that they would be asked to report process following the task. These subjects would have no reason to fix processing information in LTM for retrieval and presumably had less information available to report (Garner, 1988).

On closer examination, the views which at a superficial level seem quite divergent, are actually consistent. The model of verbal reporting proposed by Ericsson and Simon (1984) would predict that under the circumstances in which Nisbett and Wilson elicited verbal reports, the reports would not be expected to be valid or reliable. Nisbett and Wilson were justified in finding that reliable reports were not possible in these circumstances, but were not justified in generalizing their findings to all cognitive tasks.

A second issue emerging from an examination of evidence underlying these two views on verbal report data is that verbal reports are not a single phenomenon. Cohen (1987) identifies three distinct types of verbal reports: (1) self-report (an account of one's beliefs about how one would proceed in a particular cognitive activity); (2) self-observation (a retrospective account of how one proceeded in the recent processing of a specific cognitive activity); (3) self-revelment (a concurrent account of what one is thinking as a cognitive activity is completed). Although introspection ["any procedure that asks the subject to think about his or her mental processes" (Kellogg, 1982, p.142)] is inherent in each of these forms of verbal reports, Ericsson and Crutcher (1991) further differentiate the nature of these three kinds of reports in an effort to distance the perception of verbal reports from the sense in which introspection was applied by the structuralists. The structuralists' use of introspection (e.g. Titchner, 1910) involved training subjects to provide detailed analysis of cognitive processes which went far beyond 'heeded information' (Dellarosa, 1988). Ericsson and Crutcher (1991) conceptualize self-report as introspection: a detailed description and analysis of process

by trained subjects taken at face value by the researcher. In this narrower sense, introspection does not rely on specific recall and is more susceptible to restructuring by inference than other forms of report (Ericsson & Simon, 1984). Ericsson and Crutcher (1991) distinguish retrospective reports (self-observation) and concurrent verbal protocols (self-revelment) from introspection, in that these types of verbal reports are limited to the information heeded and can be validated by analysis of different data sources or accounted for by theory. Ericsson and Simon (1984) limit their use of the term verbal reports to include only retrospective reports and concurrent verbal protocols and view these two forms as distinct, subject to different threats to validity and reliability. It is in this sense that the terms verbal report data, concurrent verbal protocol and retrospective report are used in the present study.

In their evaluation of verbal report data, Nisbett and Wilson did not distinguish among concurrent verbal protocols, retrospective reports and introspection. In fact, they collected primarily retrospective report data but conceptualized them in a more general sense as verbal data and generalized their findings to all verbal data. As indicated in subsequent sections on concurrent verbal protocols and retrospective reports, there is wide theoretical and empirical support for specifying the character and constraints of different forms of verbal reports.

A third conceptual issue relevant to the use of verbal data is related to the fundamental nature of verbal report data. An important characteristic of verbal data is that it taps the subject's knowledge of cognitive processing rather than the researcher's expectations (White, 1980) and it does so in the subject's own words and meanings

(Lythcott & Duschul, 1990). Although this characteristic introduces inter-subject variability in the data base, it also captures a much wider range of insights into processing than product analysis or observation (Cohen, 1987; Russo, Johnston & Stephens, 1989). Research designed in an information processing framework, using verbal data is typically open to the contribution of that data to the analysis process (Larkin & Rainard, 1984). In the research described by Nisbett and Wilson, a priori decisions were consistently made about which aspects of a task were salient and which responses would be correct (Smith & Miller, 1978). These decisions effectively limited the potential of the verbal report data obtained and raise the question of whether the threat to validity lies within the data or the way data collection and analysis was constrained by the researchers.

In summary, the discrepancies between the position taken by Nisbett and Wilson (1977) and that proposed by Ericsson and Simon (1984) are not founded as much on the fundamentals of verbal report collection and analysis as it is on the failure of Nisbett and Wilson to specify the type of verbal report they used or the nature of the information being tapped. Their paper was important however, in that their criticisms have yielded a clarification and specification of the constraints which guide the valid collection and interpretation of concurrent verbal protocol and retrospective report data. Despite the rebuttals and subsequent elaboration and specification of verbal report collection, the broad criticisms levelled by Nisbett and Wilson still influence the perceptions of many researchers. For this reason, the theoretical and empirical underpinnings for concurrent verbal protocol and retrospective reports are summarized below. These summaries

include a conceptualization of the methodology based on information processing theory, the identification of possible threats to data validity and reliability and empirically based recommendations to minimize these threats in the implementation of each methodology.

### Concurrent Verbal Protocols

Concurrent verbal protocols (CVP) involve reporting problem solving activity aloud as it occurs. From an information processing theory perspective, this method of "thinking aloud" while performing a task results in the verbalization of the inner language of short term memory (STM) activity during the problem solving process. The information available for verbalization is limited to that information heeded in the solving process (Ericsson & Simon, 1984; Weilde & Wagner, 1982). The extent of heeded information is often underestimated (White, 1980) and may include what the problem solver is doing, what information is searched and what strategies are utilized (Ericsson & Simon, 1984; Garner, 1988). The requirement for direct reporting from STM, without editing or theorizing, minimizes the demand on STM resources and is essential to the veridicality and reliability of the verbal data produced (Ericsson & Simon, 1984; Newell & Simon, 1972). Requirements to explain thinking or to report only certain aspects of thinking go beyond direct reporting of heeded information from STM and may alter the normal processing path (Ericsson & Simon, 1984; Hayes & Flower, 1983; Poulisse et al., 1987; Russo et al., 1989). The reports generated under these conditions will not be complete (Duncker, 1945). Only the traces of thinking that were heeded can be verbalized and, consequently, automated or parallel processing cannot be reliably reported

(Afflerbach & Johnston, 1984; Ericsson & Simon, 1984; Shiffrin & Schneider, 1977).

Neither will all heeded information be reported because verbalizations are further limited by the processing capacity of STM to concurrently think and report. Some information will be lost due to the lag in reporting and competing demands for processing resources (Weilde & Wagner, 1982). Since data are limited to what was verbalized, they produce not a full account, but high density indices of information processing which permit tracing of the mechanics and immediate control of process (Byrne, 1983; Ericsson & Simon, 1984).

This theoretical representation of concurrent verbal reports raises two major threats to validity: reactivity and veridicality (Russo et al., 1989). Reactivity occurs when reporting changes processing during a cognitive activity. Veridicality refers to the truthfulness of a report which may be threatened by the omission, restructuring or fabrication of information. These threats, together with challenges to data reliability in obtaining consistent kinds of information within and between subjects and in interpreting that information, must be taken seriously by users of the methodology. Following an extensive review of the relevant literature, Ericsson and Simon (1984) conclude that, while these threats exist, their debilitating effects can be minimized by careful attention to possible threats to validity and reliability during the collection and interpretation of CVP data. They have proposed measures to minimize these threats and conclude that when these constraints are understood and implemented, concurrent verbal protocols accurately represent and do not alter cognitive processing (Ericsson & Simon, 1984).

While Ericsson and Simon have made the most substantial contribution to developing theoretical support for verbal reports, researchers in diverse fields have also contributed to developing a body of empirical evidence to support practical guidelines for the collection and analysis of verbal report data (reading, e.g. Afflerbach & Johnston, 1984; metacognition, e.g. Meichenbaum et al., 1985; artificial intelligence and information processing, e.g. Newell & Simon, 1972; second language training, e.g. Grotjahn, 1987). Their collective empirical findings are summarized in the practical guidelines to maximize reliability and validity of CVP data outlined below.

The constraints which maximize the validity and reliability of CVP data emanate from both theoretical and empirical evidence. These constraints apply to the following aspects of data collection and analysis:

(1) Instructions. Instructions to participants must clearly emphasize a general "reporting" of thinking and not require subjects to report specific aspects of thinking or to explain or justify the thinking process (Ericsson & Simon, 1984; Garner, 1988; White, 1980). Instructions should de-emphasize the product of thinking and emphasize process (Larkin & Rainard, 1984). Moreover, it is the participant's knowledge of process in his or her own words that is of particular interest (White, 1980). The participant should be informed only of the general purpose of the research (Haastrup, 1987). Instructions to participants should be standardized so that all participants receive the same instructions (Ericsson & Simon, 1984). These measures minimize interference with cognitive processing and reactivity to the research context.

(2) Warm-up exercises. Warm-up exercises are essential (Russo et al., 1989). Firstly, they ensure that researchers and participants share the same understanding of what kind of data is required (Ericsson & Simon, 1984; White, 1980). Participants frequently have difficulty in providing concurrent rather than retrospective reports and practice can distinguish the two types of information (Cohen & Hosenfeld, 1981). Secondly, practice relieves anxiety which may interfere with task performance and makes participants feel more comfortable in reporting their thinking (Ericsson & Simon, 1984; Haastrup, 1987). Thirdly, practice minimizes the frequency of interruption or prompting during protocol collection (Afflerbach & Johnston, 1984). The procedures for the warm-up sessions should be standardized (Ericsson & Simon, 1984).

(3) Probes during CVP Collection. Comments by the researcher during CVP collection should be infrequent and neutral (Ericsson & Simon, 1984; Larkin & Rainard, 1984). Interruption of processing should be minimized (Fischer & Mandl, 1982; Kellogg, 1982; Russo et al., 1989). Prompts are usually necessary only if the participant ceases to verbalize and researchers should take care not to cue behaviour by prompting or to prompt some behaviours and not others (Garner, 1988). To avoid prompting effects, neutral and unobtrusive prompts such as "Keep talking" are preferred to "What are you thinking?" (Ericsson & Simon, 1984).

(4) Tasks. Characteristics of the task can influence verbal reports (Ericsson & Simon, 1984; Kellogg, 1982). Simple or familiar tasks are processed by well-learned, automaticized routines which are not likely to be heeded in STM and verbalizations will contain meagre information. Cognitive tasks which maximize the generation of rich and

valid data are tasks which require verbal encoding (Ericsson & Simon, 1984; Hastrup, 1987) and which are likely to require deliberate, conscious and goal-directed cognitive activity (Kellogg, 1982; Sternberg, 1981). The tasks should be novel and moderately difficult so as to elicit conscious processing (Ericsson & Simon, 1984; Smith & Miller, 1978; Shiffrin & Schneider, 1977), but not so difficult as to stymie reporting (White, 1980). These conditions optimize the likelihood that processing will be reported directly from STM and maximize the richness of the data.

(5) Data analysis. Measures taken to maximize validity and reliability in data collection must be maintained in data analysis. These measures are described in detail later in the chapter, but three major guidelines derived from the research literature include the following. Verbal data should be transcribed verbatim capturing as much verbal nuance such as pauses, emphases and tone as possible (Afflerbach & Johnston, 1984; Ericsson & Simon, 1984). Coding is necessary to reduce large volumes of data and to facilitate cross-case analysis, but should be achieved with a minimum loss of validity. To maximize validity, the coding grid should be developed from data, represent theory and be checked against further data (Afflerbach & Johnston, 1984, Ericsson & Simon, 1984). The assessment of the reliability of the coding process is important (Kail & Bisanz, 1982) and the use of two or more independent coders can enhance the reliability of data coding (Larkin & Rainard, 1984; Ericsson & Simon, 1984).

The CVP methodology has been used to document the problem solving process in a number of domains, including: physics (e.g. Larkin, McDermott, Simon & Simon, 1980); mathematics (e.g. Schoenfeld, 1985); reading (e.g. Lundeberg, 1987); writing

(e.g. Hayes & Flower, 1983); and to a lesser extent, in biology (e.g. Smith, 1988); political science (e.g. Voss et al., 1983); and teaching (e.g. Swanson, O'Connor & Cooney, 1990). In the present research, the CVP methodology meets the requirement to access strategy use with a minimum of process disruption, but falls short of providing information on the broader spectrum of strategy knowledge (Kuipers & Kassirer, 1984). It is not possible to gain more specific kinds of information within this methodology because of (1) constraints on instructions to the solver and (2) the fact that interrupting the solving process to ask questions or clarify statements would disrupt processing. To gain additional information about strategies or knowledge associated with their use, a second methodology is required.

### Retrospective Debriefing Reports

Retrospective debriefing (RD) reports provide a second data source from which to access information about EC strategy knowledge. Retrospective reports are the participant's account of the actions and thoughts remembered from a cognitive activity, verbalized following that activity (Ericsson & Simon, 1984; Rowe, 1985). In retrospective debriefings, these reports are facilitated by questions from the researcher. In the context of information processing theory, RD reports may involve some information from short term memory if initiated immediately following a task, but usually involve the retrieval and verbalization of the episodic memory of a specific activity which has been heeded in STM and subsequently stored in long term memory (LTM). In order to tap episodic memory directly, it is essential that an actual processing activity precedes

the RD, and that it is not based on a hypothetical situation (Ericsson & Simon, 1984).

The kinds of information that may be stored and retrieved include the memory of instructions, information considered and strategies utilized (Ericsson & Simon, 1987).

Like CVP reports, RD reports will not be complete. Because they originate from information heeded in STM, they are subject not only to the STM constraints which apply to CVP reports but in addition, to the constraints of LTM. Not all information heeded in STM during processing will be fixed in LTM (Hayes & Flower, 1983) and retrieval from LTM is fallible (Ericsson & Simon, 1987). This kind of retrieval is more problematic than verbalization directly from STM, because reports are often not limited to a single episodic memory and may represent a generalized conceptualization of a processing task, rather than the specific episode being studied (Ericsson & Simon, 1984; Garner, 1988; Newell & Simon, 1972).

The primary threats to the validity of RD data are similar in nature, but more serious than those to CVP data. The threat of reactivity is similar and can be minimized by the guidelines reviewed for CVP data. The threat to veridicality is heightened in RD reports because (1) less of the information heeded during processing is available in LTM; (2) interaction with the researcher is more extensive in the generation of data and may bias the report; and (3) there exists the possibility that the report may consist of specific episodic memory or be embellished by inference from past processing experiences (Newell & Simon, 1972) and rationalization of the process by the problem solver (Rowe, 1985). These concerns for validity contribute to concerns for the reliability of such data. Critics are justified in asking how dependable data that are susceptible to incompleteness,

embellishment and researcher bias can be (Filder, 1983; Poullisse et al., 1987). As in the case of CVP data, these challenges to validity and reliability must be defended and their risk minimized in the implementation of the methodology.

The theoretical account of retrospective reporting developed by Ericsson and Simon (1984) and empirical evidence on the use of retrospective reports address these validity and reliability concerns. The cumulative evidence indicates that, under certain conditions, data from RD reports have been found to be valid and reliable. In addition to the conditions which apply to CVP reports, further conditions apply to RD reports. The following additional constraints address the risks that reports will include information derived by inference rather than direct reports from episodic LTM and that reports will be biased by interaction with the researcher (Ericsson & Simon, 1984; Hastrup, 1987; Poullisse et al., 1987) :

(1) Instructions. It is further recommended that the importance of reporting only what can be remembered from the specific processing event (Ericsson & Simon, 1984) and honesty in reporting be emphasized to participants (Adair & Spinner, 1979).

(2) Eliciting the report. Retrospective reports should be elicited as soon as possible following the processing activity to be reported (Ericsson & Simon, 1984; Garner, 1988; Kellogg, 1982; White, 1980). Requests for reports should focus on what can be remembered by the participant about the specific processing event. If multiple tasks precede reporting, they should not be similar (Ericsson & Simon, 1984). These constraints maximize access to episodic memory and accurate reporting.

Probes play a greater role in the generation of retrospective reports and are perceived both as an advantage in collecting and verifying data (Ericsson & Simon, 1987; Grotjahn, 1987; Larkin & Rainard, 1984) and a risk to validity and reliability (Garner, 1988; Poulisse et al., 1987). The RD methodology allows the researcher to probe more deeply into a processing episode which may only be revealed in part by CVP data and to undertake a "cross-examination" of the process report to explore the broader range of strategy knowledge which mediates processing (Kuipers & Kassirer, 1984). Probes such as questions and references to specific moments in preceding processing and reporting can serve as retrieval cues which enhance the richness and veridicality of data (Adair & Spinner, 1979; Ericsson & Simon, 1987; Poulisse et al., 1987). Researchers may verify their interpretations of the report with the participant, enhancing the validity of the data. Probes become a threat to validity however, when they constrain the spontaneous report of the participant, ask for more information than has been heeded and remembered, or when reporting is biased by leading questions (Ericsson & Simon, 1984; Garner, 1988).

A methodological balance must be struck in which retrieval is maximized while maintaining a non-leading focus on the participant's knowledge of the event and optimizing participant-initiated reporting (Haastrup, 1987). The interviewing techniques which facilitate this type of retrospective debriefing can be profitably informed by the general principles of research interviewing. These principles include: a focus on "which" or "what", rather than "why" in eliciting information (e. g. Meichenbaum et al., 1985; Spradley, 1980); a matter-of-fact, non-evaluative posture in guiding the report (Shure & Spivack, 1978); and the use of puzzled responses and requests for clarification

(Karoly, 1981). Specific guidelines for accessing knowledge and thinking based on specific incidents are given by Bell, Osborne and Tasker (1985). Under the conditions for instructing participants and eliciting RD reports outlined above, valid and reliable data can be elicited (Ericsson & Simon, 1987; Poulisse et al., 1987).

(3) Data analysis. In addition to the general guidelines to enhance validity and reliability identified for CVP data analysis, RD data can be analyzed for their internal consistency (Ericsson & Simon, 1984) and proportion of participant initiated responses (Haastrup, 1987). Data which are not inter-subjectively observable can be checked against directly observable behaviour (Grotjahn, 1987).

Although RD data have been, in the past, characterized as less reliable (e.g. Fidler, 1983) and of lower quality than CVP data (Byrne, 1983; Ericsson & Simon, 1984), the most recent literature on their relative merit is more favourable (Ericsson & Crutcher, 1991; Ericsson & Simon, 1987; Poulisse et al., 1987). This shift is primarily due to the accumulation of theoretical and empirical evidence which specifically defines the methodology and the conditions for its use. Provided that these conditions are understood and observed, RD data are valid, reliable, and can provide information about cognitive processes which is not available through other means (Ericsson & Crutcher, 1991; Poulisse et al., 1987).

### CVP and RD as Complementary Methodologies

The review of the literature prescribing the use of the CVP and RD methodologies also supports the complementary use of these two approaches to collecting data. With

both CVP and RD data, only information heeded by the problem solver has the potential to be reported. Therefore, neither of these reporting methods can be expected to be complete. Used together, however, RD data enhance the completeness of CVP data and CVP data can be used guide the collection of RD data (Haastrup, 1987). The two data sources can also provide opportunities for reciprocal validation. RD data can be utilized to validate and clarify the interpretation of CVP data (Grotjahn, 1987; Poulisse et al., 1987) and CVP data can provide validation for RD data (Ericsson & Simon, 1984; 1987). These advantages are consistent with the benefits of using multiple data sources to achieve convergent validation of the description of thought processes (Ericsson & Simon, 1987). Triangulation based on different data sources is particularly recommended in the valid and reliable assessment of metacognitive knowledge (Garner, 1988; Meichenbaum et al., 1985) and executive control strategy knowledge is a form of such knowledge. Based on a review of the research literature and the results of the pilot study (Taylor, 1990), both methodologies are consistent with the conceptual framework presented here and, when employed in a complementary fashion, elicit more informative data than either method used alone. For these reasons, it was decided to utilize the dual CVP/RD methodology, observing the conditions for the collection and analysis of CVP and RD data reviewed above.

### **Population and Sample**

The population chosen was university professors and university students registered in third year courses. This population was chosen because the gap between the problem solving strategies of professors and students is a major concern in university teaching and is well documented in the research literature ( e.g. Chiapetta, 1976; Glaser, 1984; Poduska & Phillips, 1986; Schoenfeld, 1985). A second body of literature indicates that deficits in EC strategies are a common source of difficulty in problem solving at the university level, as elsewhere (e.g. Bloom & Broder, 1950; Derry & Kellis, 1987; Schoenfeld, 1983). The effective use and acquisition of such strategies has been observed to develop with experience, so as to be best learned and retained by experienced students (Pressley et al., 1984). Students at the third year level were chosen in order to tap a level of expertise not commonly included in expert-novice studies. The strategy knowledge of these intermediate level students will help characterize strategy knowledge at this level for the purpose of better understanding the teaching task and may contribute to a model of strategy knowledge useful at the student level. These factors designate university level students and professors as an appropriate population for a comparative study of EC strategy knowledge.

The sample selected in this study consisted of nine professors of biology [BP] (3 females, 6 males) and nine students [BS] (5 females, 4 males) registered in third year classes in biology and a further nine professors of political science [PSP] (4 females, 5 males) and nine students [PSS] (6 females, 3 males) registered in third year classes in

political science. The groups are not balanced with respect to sex due to the unavailability of volunteers in some cells. However, because this was an exploratory study, it was considered appropriate to include both sexes in the sample. In the event that sex differences are suggested by the data, future research avenues could be opened. The sample size is larger than often used in similar research in order to provide a sufficient number of data files for coding grid development and subsequent testing of the grid on further data analysis.

All thirty-six participants entered the study on a volunteer basis. Classes at the third year level in each domain received a brief presentation on the nature and requirements of the study and, over the following week, were provided with opportunities to volunteer. Professors were notified of the study in writing and brief presentations, and individually invited to participate. This method of recruitment resulted in committed participants (Ericsson & Simon, 1984; Poulisse et al., 1987) who judged themselves able to provide evidence of their own problem solving knowledge (Byrne, 1983; Morse, 1989).

The domains of political science and biology were chosen on the basis of two criteria. The first criterion was that the two domains be perceived as distinct from each other in the "real world phenomena" they include (Carey, 1985). The second was that neither domain has been extensively studied with regard to problem solving. The literature on problem solving in political science is based primarily on the work of one group (Voss et al. 1983) and corresponding work in biology focuses primarily on problem solving in genetics (e.g. Hackling & Lawrence, 1988; Smith, 1988; Smith &

Good, 1984). On the basis of these two criteria, biology was selected as an example of a natural science and political science was selected as an example of a social science.

### **The Experimental Tasks**

Each participant was required to complete two experimental tasks. The tasks consisted of two problem scenarios, the selection of which was guided by three major criteria:

- (1) Each scenario should be judged by domain experts to represent valid problems in the intended domain.
- (2) Each scenario should satisfy the defining criteria for ill-structured problems. In summary, these criteria are that: the initial and/or goal state may not be well defined; the problem solver must contribute information to the solving process; there is more than one sequence of problem solving steps which could result in a solution; and there may be more than one correct solution (Reitman, 1965; Simon, 1973).
- (3) The problem scenarios should be constructed so as to be interesting and approachable across a broad range of expertise. Non-experts in the problem domain should be able to deal with the scenario using limited or common sense knowledge, whereas experts may evoke a much more sophisticated knowledge base in solving the problem.

Previously constructed problems meeting these requirements were not available, and therefore, novel tasks were developed for the purpose of the present study. To ensure that the selection criteria were met in the problem development process, the following sequence of scenario construction was followed. For each problem, a panel of three domain experts (university professors) was approached to design two problems, according to the above set of criteria. This step was taken to ensure the domain integrity of each task. The problems were reviewed by the design panel and judged to meet the design criteria. These expert panels were asked to select the problem they judged to be more strongly representative of the domain. As a result, Experimental Task 1 (See Table 1) was chosen as the problem scenario for biology. The political science tasks were judged to be equally representative of the domain and Experimental Task 2 (See Table 1) was selected as the political science problem scenario on the basis of its potential to elicit data during the pilot study.

Table 1

The Experimental Tasks

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Task 1

In a remote 100,00 kilometre area of Northern British Columbia, a chain of low mountains forming numerous valleys has traditionally been rich in wildlife, including large populations of moose and wolves. Historically, this flourishing wildlife supported the hunting and trapping practices of the area's native people. More recently, these resources supported the establishment of small towns with economies based on cattle farming and out-fitting for big game hunting.

The establishment of these towns has affected the populations of moose and wolves in particular. About 20 years ago, wolves were hunted almost to extinction by farmers, resulting in a ban on wolf hunting which is now entering its tenth year.

Big game out-fitters are currently complaining to provincial authorities that since it became illegal to intentionally kill wolves, the wolf population appears to have increased, and the moose population decreased, to the extent where hunters are going elsewhere to hunt. They argue the wolves are decimating the moose and they claim that the most effective way to revive the faltering economy is to revoke the ban on killing wolves.

If you were the person assigned to resolving this case, how would you go about deciding on a solution to the declining moose population problem?

Task 2

A maritime city of about 200,000 has, in the past, enjoyed a stable workforce which has allowed successive generations of a family to earn a livelihood. In this stable environment, family responsibilities such as child rearing have been shared among extended family.

The industrial job base has been steadily eroded over the last decade, and the sagging economy is altering the character of the city. Members of many families who have been long time residents of the city have been forced to find employment elsewhere, disrupting extended family networks.

One of the problems to emerge following this out-migration is that a particular group of about 60 single mothers have found themselves on the margins of society. The women in this marginal group have a history of out-patient psychiatric care and have been intermittent residents of half-way houses. These women have received limited education and, if they are employed, accept menial work and low wages. These circumstances give rise to low self-esteem and consequently, these women assume the role of 'victim' in assessing their situations and feel powerless to act on their own to change their social situations.

As a person assigned to resolving this case, how would you propose to help these women become reintegrated into society?

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To this point the problem scenarios had evolved independently of each other, but were judged by their developers to meet a common set of criteria. The second phase of task development was to establish the equivalency of the two problem statements based on their global structure and readability levels, while maintaining the integrity of the original problem scenarios. In this phase, the researcher adapted the original problem statements so that each scenario:

- (1) was similar in length (Task 1 = 205 words; Task 2 = 209 words);
- (2) exhibited a similar global structure: a historical context followed in sequence by a description of a current situation, the presentation of a problem, and the request to solve.
- (3) was presented at college level readability as measured by two different measures of readability. The two measures were the Fry Readability Graph (Estes & Vaughan, 1985) and the Dale-Chall Readability Formula (Dale & Chall, 1958). These measures estimate the general level of difficulty of a text and, while they do not take into account the relative nature of difficulty as a function of individual reader's interaction with the text, they are useful in estimating the difficulty of reading tasks (Singer & Donlan, 1980) and in comparing the readability of different tasks (Estes & Vaughan, 1985).

A third phase of task development was undertaken to determine the degree to which the independently constructed scenarios would be judged equivalent with regard to the four attributes of ill-structured problems which guided their development. Both tasks

were presented to a panel of twelve graduate students who judged them equivalent on the basis of the approachability and ill-structuredness criteria listed above. The level of agreement between judges was high: eleven of twelve judges reported that the problems could be approached by both novices and experts and a minimum of ten of twelve judges agreed that the two scenarios met each of the four criteria for ill-structuredness. Based on the responses, the two scenarios were judged equivalent with regard to the design criteria.

Finally, both tasks were field tested with participants from the population selected for this study (but not participating in the actual data collection) to determine the potential of each task to elicit the type of data that would be required to meet the research objectives. These field tests confirmed the validity of Task 1 and Task 2, in that they elicited high effort, a high degree of involvement with the task and resulted in verbalizations containing evidence of the solvers' EC strategy knowledge.

## **Data Collection and Preparation**

### **Data Collection Procedure**

The procedure for collecting data was designed to capture with maximum validity and reliability the spectrum of strategy knowledge originally described by Pressley et al. (1985): specific strategy knowledge; general strategy knowledge; and strategy acquisition knowledge. Data were collected on an individual basis from each participant during a single session which typically required one and one half to two hours. The session took place in a quiet room, free from interruption. The protocol implemented in each session

was the same, and followed the recommendations for concurrent verbal protocol collection and retrospective debriefing reviewed earlier in this chapter. The procedure can be described by the following sequence of steps:

1. Consent. The participant read and signed the consent form which was made available before the data collection session (Appendix A).

2. Instructions. Each participant received a standardized set of verbal instructions from the researcher on the type of information required and general guidelines for generating data (Appendix B).

3. Warm-up problems. Warm-up problems (Appendix B) were intended to allow the participant to become comfortable with thinking aloud while solving a problem. During a standardized warm-up phase, participants were free to ask questions and discuss any concerns they had about the procedure or the kind of data being generated. The warm-up problems continued until the participant reported being comfortable with verbalizing the problem solving process as it occurred. The warm-up period varied from ten to twenty minutes.

4. CVP for the first experimental task. The first of two experimental tasks was then presented. The order of presentation of the tasks was randomly assigned. Each participant worked on the task while verbalizing as much as possible the thoughts that were going through his or her mind. All verbalizations were audio-taped. During this phase of the data collection, the problem solver worked independently and the researcher intervened only to prompt the solver to "keep talking". This intervention took place only when silences exceeded ten seconds and was required in only three of thirty-six protocols.

Pencil and paper were made available and any notes made by the problem solver were retained for analysis.

Because CVP data provided the basis for retrospective debriefing of each experimental task, the researcher, in addition to monitoring the extent of verbalization during each CVP segment, also attended to the content of the CVP data. During the generation of CVP data, the researcher systematically noted overt problem solving behaviours and, to a lesser extent, salient comments (e.g. "I guess I agree with this enough to work on it." PSP-8) which would be used as reference points in retrospective debriefing.

5. Retrospective report on the first task. On completion of the first task, the researcher immediately asked the participant to describe in his or her own words how the problem was solved. In so far as possible, this report was spontaneous, with a minimum of probes from the researcher. If questions were necessary to obtain the report, they were kept simple: "Can you tell me more? What do you mean? What were the most important things you did in solving the problem?" Occasionally, participants lost track of where they were in their account and asked to be reminded of the point they had reached in their description. Throughout this retrospective account, the researcher noted points which might be clarified or elaborated as the retrospective debriefing of the task continued.

6. Discussion of the first task. This retrospective report was immediately followed by a semi-structured discussion with the participant on the strategies which appeared to arise in the CVP and the retrospective report data. This discussion was open

in that questions always derived from the actions taken by the solver during the problem solving process and was flexible in scope and depth, depending on the responses of individual solvers. It was structured in that it was guided by a general questioning framework (Appendix C) intended to maximize the yield of data and to ensure the collection of consistent broad categories of data from each participant. This guiding framework was based on the phases of the problem solving process: understanding the problem, gathering relevant information, planning a solution, carrying out the plan and verifying the outcome ( e.g. Bransford & Stern 1984; Baron, 1985). Within this framework, the researcher attempted to elaborate the problem solving knowledge of each participant based on the observations made during CVP data collection and each problem solver's account of his or her interaction with the first task. The researcher also used this discussion to clarify her own perceptions and assumptions in order to reduce the level of inference in interpreting the data.

This semi-structured approach to data collection, while it maximizes the yield of information from each problem solver, requires expertise and an acute awareness of the interviewing process on the part of the researcher. Apart from following the general principles of interviewing reviewed when developing the methodology, the researcher addressed the threat of bias in selecting the behaviours to be probed in debriefing by systematically noting as many behaviours as could be recorded during the CVP segment and insuring that each of these behaviours was addressed in the debriefing process, either in the spontaneous comments of the solvers, or by direct probes. The methodology and

skill required to consistently follow this data gathering approach was developed in early "dry runs" of data gathering and practised during the pilot study (Taylor, 1990).

7. CVP for the second experimental task. Same procedure as in (4).

8. Retrospective report for the second task. Same procedure as in (5).

9. Discussion of the second task. Same procedure as in (6).

10. More general questions regarding strategy knowledge. In this phase of data collection, participants were asked to go beyond the solving of the two particular problems presented in the study and comment more generally on whether they like problem solving, the contexts which influence their problem solving process and how they acquired problem solving knowledge. The responses to these more general questions, the discussion of each problem solving episode (6 and 9) and the retrospective report for each problem solving episode (5 and 8) constitute the retrospective debriefing session (RD) data referred to throughout the text which follows.

11. Problem ratings. Because the degree of ill-structuredness of a problem is relative to the individual problem solver (Reitman, 1965), each participant was asked to rate the problems they had worked on with regard to four of the defining attributes of ill-structured problems outlined earlier in this chapter (Appendix D).

### Data Preparation

The primary data source generated using the procedure described was the audiotapes of the participants' concurrent verbal protocols (CVP) and retrospective debriefing sessions (RD). These data were complemented by notes made by participants

during the CVP, the participant's ratings of the problems with regard to ill-structuredness and notes made by the researcher at each session.

Analysis of the CVP and RD data required the verbatim transcription of the audio-tapes made during each session. Following the guidelines of Ericsson and Simon (1984), final transcripts replicated verbalization as carefully as possible, including the pauses, hesitations, exclamations and partial sentences which characterized the verbalizations of the participants. Minor editing procedures were employed (1) to delete names and personal references that would threaten the anonymity of participants and (2) to clarify anaphoric references. To facilitate the coding process, verbalizations were transcribed as short lines of data (40 characters wide), and the lines of each data file were consecutively numbered. Where possible, observations of note making were integrated in the transcript. Finally, the CVP portions of each data file were timed and each five-second interval was noted in the protocol, enabling the representation of the coded problem solving process in real time (actual time elapsed). This timing facilitated later stages of data analysis. At this point, the data files were ready for coding.

Other data sources were tabulated in forms that would facilitate data analysis. The notes made by the problem solvers, in addition to being integrated with the data files, were characterized by their extent, content and use during the problem solving process. The ratings of each task by participants with regard to the attributes of ill-structured problems were also tabulated. These complementary data sources, together with notes made by the researcher during each session, were included in the data analysis.

### The Development of the Coding Grid

In the present study, the purpose of the coding grid was two-fold: (1) to provide a means to describe, on a real time line, the problem solving patterns manifested during the CVP and (2) to capture the EC strategy knowledge evidenced in the problem solving process and in the subsequent RD data. Since the tasks on which the data was generated were novel, a coding grid which would be functional in analyzing data from these tasks was required.

The development of the coding grid followed the procedures outlined by Ericsson and Simon (1984) and elaborated by Rowe (1985). The taxonomy of problem solving strategies represented in the grid is derived from the theoretical framework and the data collected. In the development of this particular grid, the theoretical framework sets the broad categories of problem solving behaviour, and these categories are elaborated from specific strategies observed in the data.

### The Theoretical Component

For reasons cited earlier, the level of analysis selected in the present study is the executive control (EC) level. EC strategies have been defined to include those goal directed procedures that are planfully or intentionally evoked prior to, during or following the problem solving episode for the purpose of monitoring, directing or evaluating the problem solving process. In this context, monitoring is characterized as an awareness of any aspect of the problem solving process. Directing is characterized as

actions taken during the solving process. Evaluating is characterized as any attempt to assess the problem solving effort at any point during the problem solving process. These three categories of strategies are very broad and may be evoked at various stages in the problem solving process. In the present study, it is not only their generic use which is of interest, but a more specific articulation of how these strategies are manifested, and where and when in the problem solving process they are utilized.

This depth of analysis demands a two dimensional framing of the coding grid. On one dimension are the generic executive control strategies of monitor, direct and evaluate. On the second dimension are the major phases which characterize the problem solving process. There are many different descriptions of these phases (e.g. Baron, 1985; Bransford & Stern, 1984; Sternberg, 1980), but all descriptions share many attributes. The most appropriate global taxonomy for data collected in this study was determined in a recent pilot study designed to test the proposed methodology (Taylor, 1990). Four data files were analyzed to determine which representation of global problem solving processes provided a good fit to the data and facilitated the study of executive control strategies. As a result of this preliminary work, the description chosen to frame the coding grid draws on the one used by Schoenfeld (1985). Although designed for the analysis of verbal protocols of mathematics problems, Schoenfeld's global taxonomy of read, analyze, explore, plan, implement and verify provided a strong framework for the present coding grid. These global strategies captured the nature of the solving process employed in the solving of the ill-structured problems presented in the present study and allow for the real-time coding of the CVP data collected. Schoenfeld's taxonomy focuses

attention on the control of the problem solving process and therefore, is useful in the study of executive control strategy knowledge. Schoenfeld's framework was not, however, applied directly in this case. The global coding category, "new information", while important in Schoenfeld's research, was not used here where the emphasis is on the analysis of strategy knowledge. In keeping with the analysis of EC strategies within each phase of problem solving, Schoenfeld's global category of "local assessment" was incorporated into each global component of the framework.

Together, Schoenfeld's (1985) global taxonomy of problem solving behaviour and the three generic executive control strategies form the two dimensional theoretical matrix on which the full coding grid is built.

#### The Data-based Component

This theoretical framework specifies the perspective from which the data were analyzed, but it is data which should determine the specific categories to be coded (Newell & Simon, 1972). The contribution of the data to the coding grid is essential to the elaboration of the cells created by the theoretical frame. To generate the specific strategies included in the matrix which formed the coding grid, a protocol from one male and one female participant was randomly chosen from each of the four groups of participants. The CVP portions of these eight protocols were analyzed for evidence of problem solving strategies which would (1) describe the overall problem solving pattern in each case and (2) characterize the executive control strategy knowledge demonstrated by each problem solver. Strategies meeting these requirements were compiled from the

eight protocols and were organized according to the matrix provided by the theoretical framework (Figure 3). This approach allowed the coding grid to be developed from a subset of data and then tested for its validity on the entire data set.

### The Coding Grid

This matrix (Figure 3) was then transformed into a coding grid by defining each global and specific strategy and providing one or more prototype examples from the eight data files to illustrate how the definition could be applied to real data (Appendix E : The Coding Grid). A condensed version of the coding grid consisting of the coded and their definitions is presented in Table 2.

The product of the grid development process was a single coding grid which was deployed in two stages. In the first round of analysis, global strategies were assigned to segments of data using the definitions and guiding questions in Appendix F: Definitions and Guiding Questions for the Coding of Global Strategies. The definitions and questions which determine this preliminary global round of coding draw on those suggested by Schoenfeld (1985), but are not restricted to them. In the second round of analysis, data within each globally coded segment were analyzed to determine if they fit any of the categories within that global strategy in the coding grid. This system provided a means to describe (1) the problem solving process demonstrated in the CVP on a real time line and (2) the EC strategy knowledge manifested in different phases of problem solving based on CVF' and RD data. It also enabled the coder to work with a complex grid while

EXECUTIVE CONTROL STRATEGY			
GLOBAL STRATEGY	MONITOR	DIRECT	EVALUATE
<b>READ</b> <ul style="list-style-type: none"> <li>● important information</li> <li>● difficulty</li> <li>● interest</li> <li>● familiarity</li> </ul>	<ul style="list-style-type: none"> <li>● read</li> <li>● re-read</li> <li>● elaborate information</li> <li>● represent problem</li> </ul>	<ul style="list-style-type: none"> <li>● evaluate understanding</li> </ul>	
<b>ANALYZE</b> <ul style="list-style-type: none"> <li>● bias</li> <li>● assumptions</li> <li>● perspective</li> </ul>	<ul style="list-style-type: none"> <li>● identify links</li> <li>● identify sub-problems</li> <li>● identify starting point</li> <li>● historical analysis</li> <li>● restructure problem</li> </ul>	<ul style="list-style-type: none"> <li>● evaluate information given</li> </ul>	
<b>EXPLORE</b>	<ul style="list-style-type: none"> <li>● sources of information</li> <li>● existing knowledge</li> <li>● possible analogies</li> </ul>	<ul style="list-style-type: none"> <li>● select relevant information</li> </ul>	
<b>PLAN</b> <ul style="list-style-type: none"> <li>● difficulty</li> </ul>	<ul style="list-style-type: none"> <li>● outline a plan</li> <li>● consider alternatives</li> <li>● modify the plan</li> </ul>	<ul style="list-style-type: none"> <li>● evaluate the plan</li> </ul>	
<b>IMPLEMENT</b>	<ul style="list-style-type: none"> <li>● make a solution statement</li> <li>● give reasons</li> </ul>		
<b>VERIFY</b>	<ul style="list-style-type: none"> <li>● consider alternatives</li> </ul>	<ul style="list-style-type: none"> <li>● review solution</li> <li>● evaluate the limits of the solution</li> </ul>	

Figure 3. The Theoretical and Data-based Components of the Coding Grid

Table 2.

Codes and Definitions From the Coding Grid

Code	Code Definitions
R: 1	- first reading of the problem statement.
R: re	- re-reading any part of the problem statement for the information given or the task required.
R: imp	- identifying important or interesting information in the problem text during the reading stages. Important elements can be underlined, written down or mentally flagged.
R: elab	- elaborate the meaning or significance of phrases from personal knowledge during reading. Elaboration may be verbal or involve imagery.
R: diff	- monitor the degree of difficulty of the problem from a personal perspective while reading.
R: fam	- identify the problem as familiar or unfamiliar or, more specifically, by domain, process or analogy.
R: und	- any effort to determine if the problem statement is clear to the solver.
R: rep	- any effort to summarize or diagram the problem, in the process of synthesizing a representation of the problem.
R: int	- monitor whether the problem is interesting to the solver.
A: info	- critically consider the source, quality, implications or gaps in the information given in the problem statement.
A: sub	- identify subproblems within the original problem.
A: link	- consider how the elements of the problem are linked or interact.
A: per	- identify one or more perspectives from which the problem is, or can be viewed.
A: bias	- recognize personal beliefs, emotions or biases with regard to the problem situation.

<b>Code</b>	<b>Code Definitions</b>
<b>A: assm</b>	- identify the assumptions within the problem statement or in how the problem is interpreted.
<b>A: his</b>	- undertake an historical analysis to find possible causes or solutions
<b>A: start</b>	- identify a point from which to begin solving the problem.
<b>A: rest</b>	- restructure the problem using a different interpretation of given information or information other than that from the problem text.
<b>E: sour</b>	- identify possible sources of needed information.
<b>E: info</b>	- explore existing knowledge stores for information useful in solving the problem.
<b>E: agy</b>	- explore analogous situations from existing knowledge.
<b>E: sel</b>	- select information from explored areas for inclusion in the solving process.
<b>P: out</b>	- outline or diagram a framework for solving the problem.
<b>P: alt</b>	- consider possible alternative ways to solve the problem.
<b>P: eval</b>	- evaluate the likely effectiveness of the plan, either directly, or by considering implications of the plan.
<b>P: mod</b>	- modify the plan if new information or an element of the problem not previously considered is realized.
<b>P: diff</b>	- monitor difficulties encountered during the planning of a solution.
<b>I: soln</b>	- bring together the solving process in a solution statement.
<b>I: rea</b>	- provide reasons or evidence for decisions or points made in the solution statement.
<b>V: eval</b>	- critically review the solution to the problem in terms of the problem statement or plan.
<b>V: lim</b>	- recognize the limitations of the solution offered.
<b>V: alt</b>	- consider other possible solutions or explanations.

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using a small number of codes at any one time, increasing coding reliability (Schael, 1989).

Although the coding grid was designed to require a low level of inference in coding data, the coding of CVP data always involves some level of inference in interpreting problem solving behaviour. For this reason, and the reliability of each phase of the coding process was assessed. The eight data files randomly selected to generate the grid were independently coded by a second coder who applied the coding grid. The overall level of agreement for the coding of global strategies from the definitions and guiding questions was .89. The overall level of agreement was the same for each task, indicating that the protocols for Task 1 were not more difficult to code than for Task 2. Between global categories, the levels of coding agreement were .95 for read; .81 for analyze; .84 for explore; .91 for plan; .93 for implement; and .89 for verify. In resolving the differences between coders, it was found that there was some ambiguity in assigning analyze and explore codes. Consequently, the definitions of these codes were revised to clarify their separation. The full coding grid was then applied to the eight data files with an overall level of agreement between coders of .94. For Task 1, the overall level of agreement between coders was .93, and for Task 2, .95. The levels of agreement between coders for specific codes ranged from .80 to 1.0, and was generally strong, with 24/31 codes being assigned with a level of agreement between coders of .90 or higher. All differences between coders were resolved through discussion to determine possible sources of ambiguity. On the basis of the levels of agreement between independent coders, the coding grid was judged reliable and was applied to all data files.

In addition to determining the reliability of the coding grid, the rounds of independent coding also contributed to the clarification of code definitions and the separation between coding categories, as differences in the application of the coding grid were resolved between coders.

### The Coding Procedure

The coding procedure followed for the CVP portions of each file was as follows:

- (1) The CVP was read from beginning to end before the coding process was undertaken, to place coders in the context of the entire solution.
- (2) the CVP data were segmented into global categories (episodes) characterized as read, analyze, explore, plan, implement or verify. This preliminary coding process was determined by the definitions and guiding questions which characterize each category (Appendix F). These episodes constituted the basic structural units of the problem solving process and usually had clear transitions.
- (3) Within each global category, data were analyzed for specific executive control strategy knowledge using the full coding grid (Appendix E). The coding procedure remained open to the formation of new coding categories based on new data. During the full coding procedure, two new codes were added to the grid: A:start and P:diff.
- (4) Following the coding of every sixth file, the first file in that series of six was re-coded to check for slippage in the application of the coding grid. The

mean agreement between these codings was .96, indicating that little slippage had occurred.

(5) Steps (1) through (4) were repeated for the CVP of the second problem in the protocol.

The coding of RD data was more varied, because of the wider range of data elicited during this phase of data collection. These data were based on reports of strategies used in the immediately preceding problem solving episode, but also included conditional knowledge about those strategies; beliefs and attitudes about problem solving and strategy use; and knowledge of how strategy knowledge was acquired. To optimize the information available in these rich data, the full coding grid was first applied to the RD data in each protocol to maximize the yield of conditional knowledge about each of the strategies in the grid. In this round of coding, any reference to when or where to implement a specific strategy, its expected utility, degree of difficulty or track record was coded as conditional knowledge relevant to that strategy. A full inventory of conditional knowledge extracted from the data is presented in Appendix G.

The RD data was further coded according to emergent themes related to general strategy knowledge and strategy acquisition knowledge that were evidenced in RD data but not addressed in the coding grid. These themes were developed by systematically identifying (1) statements referring to beliefs about the problem solving process or self as problem solver (general strategy knowledge) and (2) statements referring to how strategy knowledge was acquired (strategy acquisition knowledge) in each protocol. The excerpts which were identified as representing general strategy knowledge or strategy acquisition

knowledge were then grouped through a process of "domain analysis" (Spradley, 1980) in which excerpts were grouped by similarity of content or function to determine categories of data and their properties. The themes which emerged from this clustering of statements were based on direct knowledge statements by each solver rather than by inferences from statements or behaviours. A full inventory these general strategy knowledge (beliefs) themes is provided in Appendix H and a full listing of strategy acquisition knowledge themes is provided in Table 13 (chapter 4). An example of a coded protocol is provided in Appendix I.

#### Consolidation of All Data Sources

Following the coding of CVP and RD data, each of the remaining data sources were analyzed first on an individual basis. The notes made by problem solvers were analyzed for their extent, content and function during the problem solving process (Appendix J). The participant ratings of the problems with regard to attributes of ill-structured problems were analyzed for instances in which the problem solver may not have perceived the problem as ill-structured (Appendix K). The researcher's session notes were analyzed for any new, corroborating or contradictory evidence. These complementary data sources were then integrated with the larger data matrix emerging from the analysis of CVP and RD data.

The integrated matrix constituted a systematic way to summarize the three major aspects of EC strategy knowledge demonstrated by each participant so that it could be represented in a form making it comparable to that of others (Miles and Huberman,

1984). The first component of the matrix consisted of colour-coded maps of the CVP portions of each protocol. These CVP maps were constructed from the transcripts of the "think aloud" portions of each protocol which had been continuously coded, based on a coding grid (Appendix E). Each solution could then be described using a sequence of assigned codes. In constructing CVP maps, specific strategy codes were placed, in sequence, on a time line depicting the actual time devoted to each strategy. Strategies belonging to each global strategy were represented in a different colour, producing a visual representation of global strategy use. An example of a CVP map is provided in Appendix L. The second information component consisted of the documentation of the conditional knowledge about strategy use which was present in the data provided by each individual (summarized in Appendix G). Each instance of conditional knowledge was coded for ease in representation during analysis. Full inventories of reported general strategy knowledge (beliefs) and strategy acquisition knowledge were similarly prepared for each case (summarized in Appendix H and Table 13). Because of their content, these inventories of general strategy knowledge and strategy acquisition knowledge were more variable in their make-up and did not use the organizational framework of the coding grid. To avoid the skewing of conditional knowledge, beliefs and strategy acquisition knowledge results by redundant reports, the total number of reports from each participant includes only the number of different items reported, and not the total number of reports. This consolidated matrix provided a rich representation of the EC strategy knowledge of each participant in a form which allowed cross-expertise and cross-domain analysis of the three major forms of strategy knowledge to take place. The results of these analyses are reported in chapter four.

## **CHAPTER 4**

### **PRESENTATION AND INTERPRETATION OF RESULTS**

The research objectives which have thus far guided data collection and analysis have been firstly, to explore the EC strategies and associated strategic knowledge demonstrated by professors and students in solving ill-structured problems and secondly, to examine differences in EC strategy knowledge across domains and across expertise. It has been postulated that EC strategy knowledge is a dynamic composite of general strategy knowledge, specific strategy knowledge and strategy acquisition knowledge. The results described here represent an attempt to capture glimpses of all three forms of strategy knowledge. These glimpses are described from the perspective of the educator's questions which precipitated this research: What are the strategies we wish our students to acquire? Which strategies are most useful in student problem solving? Which aspects of expert strategy knowledge are most often lacking in student performance and could be most effectively taught?

With this context in mind, the present chapter has been organized according to a framework which is compatible with both the data compiled and the conceptual framework supporting the research. The presentation and interpretation of the results begins with a brief overview of the nature of the data collected and the information it contained. Secondly, a characterization of global strategy use across expertise and domains is presented to form a data-based context in which the more detailed analysis of specific strategy knowledge could be situated. This organizing framework was important in itself, but also provided a bridge which linked the detailed and holistic approach taken

here with previous expert-novice studies which typically focused on this global level of analysis. Thirdly, within the context of these global patterns, the specific strategy knowledge demonstrated by solvers is elaborated. The chapter continues with the presentation and interpretation of reported beliefs relevant to strategy use and concludes with an exploration of the strategy acquisition knowledge expressed by students and professors. Because glimpses of different types of strategy knowledge have been collected, a complex body of data which required different methods of analysis was generated. To enhance clarity in the presentation and discussion of results in this complex context, each set of results is also accompanied by a focused interpretation. The focus in interpretation is on articulating those aspects of EC strategy knowledge relevant to the teaching and learning of strategy knowledge within each global strategy. A more general discussion of broader issues emanating from these results follows in chapter five. In addition to enhancing clarity, this two-phased system of interpretation permits these data to firstly, provide an empirical basis for designing effective instruction of EC strategy knowledge at the university level, and secondly, contribute to broader conceptual issues.

### **The Nature of the Data**

The dual CVP/RD methodology chosen to tap the breadth of EC strategy knowledge required to meet the research objectives produced two primary sources of data: CVP and RD reports. CVP and RD data demanded different types of interpretation

and yielded different, but complementary, types of information. The interpretation of CVP data was based on strategy knowledge inferred from problem solving behaviour (see Appendix I; Appendix L), whereas RD data interpretation was more direct, relying on explicit statements of knowledge made by each solver. In terms of the information yielded, the analysis of CVP data provided a record of strategies implemented during problem solving and, as Kuipers and Kassirer (1984) had earlier observed, reflected primarily the control of the problem solving process. These data yielded a small amount of conditional knowledge, but generally did not provide indications of other forms of EC strategy knowledge. The RD data, on the other hand, were dominated by instances of conditional knowledge, beliefs about problem solving and strategy acquisition knowledge.

Because the CVP reports provided the basis for retrospective debriefing, however, there were multiple points of overlap between the two data sources. These points of overlap provided opportunities to reduce the level of inference made in coding CVP data by verifying the solvers' intentions and meanings from RD data. Conversely, such triangulation functioned to determine the veridicality of RD data by determining its consistency with actual problem solving behaviours. This bi-directional cross-checking process was used extensively during the coding process and in elaborating the strategy knowledge of individual solvers. Although there were items of knowledge reported for which no verification was possible, and solvers reported items they were aware they did not apply in solving the experimental tasks, there were no instances where solvers claimed to use knowledge that was not consistent with their behaviour. This consistency between CVP and RD data supports the recommendation of Ericsson and Simon (1984) to

base RD reports on specific episodes of problem solving in order to maximize the reliability of the data.

A characteristic shared by both data sources is that neither form of verbal reports can be complete. Consequently, the reporting of specific knowledge items can be taken as positive evidence, but a non-report cannot be taken as evidence that the solver does not possess the knowledge in question. While this constraint is compatible with Paris and Winograd's (1990) characterization of metacognitive knowledge as knowledge which can be shared, one should be careful to distinguish between knowledge "reported" and knowledge "held". One of the constraints operating in the present study was that the results represent reported indices of EC strategy knowledge and not the solvers' full complement of strategy knowledge. Working within this constraint, the data collected can be described as providing high-density indices of the strategies actually used in solving ill-structured problems, the conditional knowledge which mediated their use, beliefs which influenced problem solving and strategy acquisition knowledge.

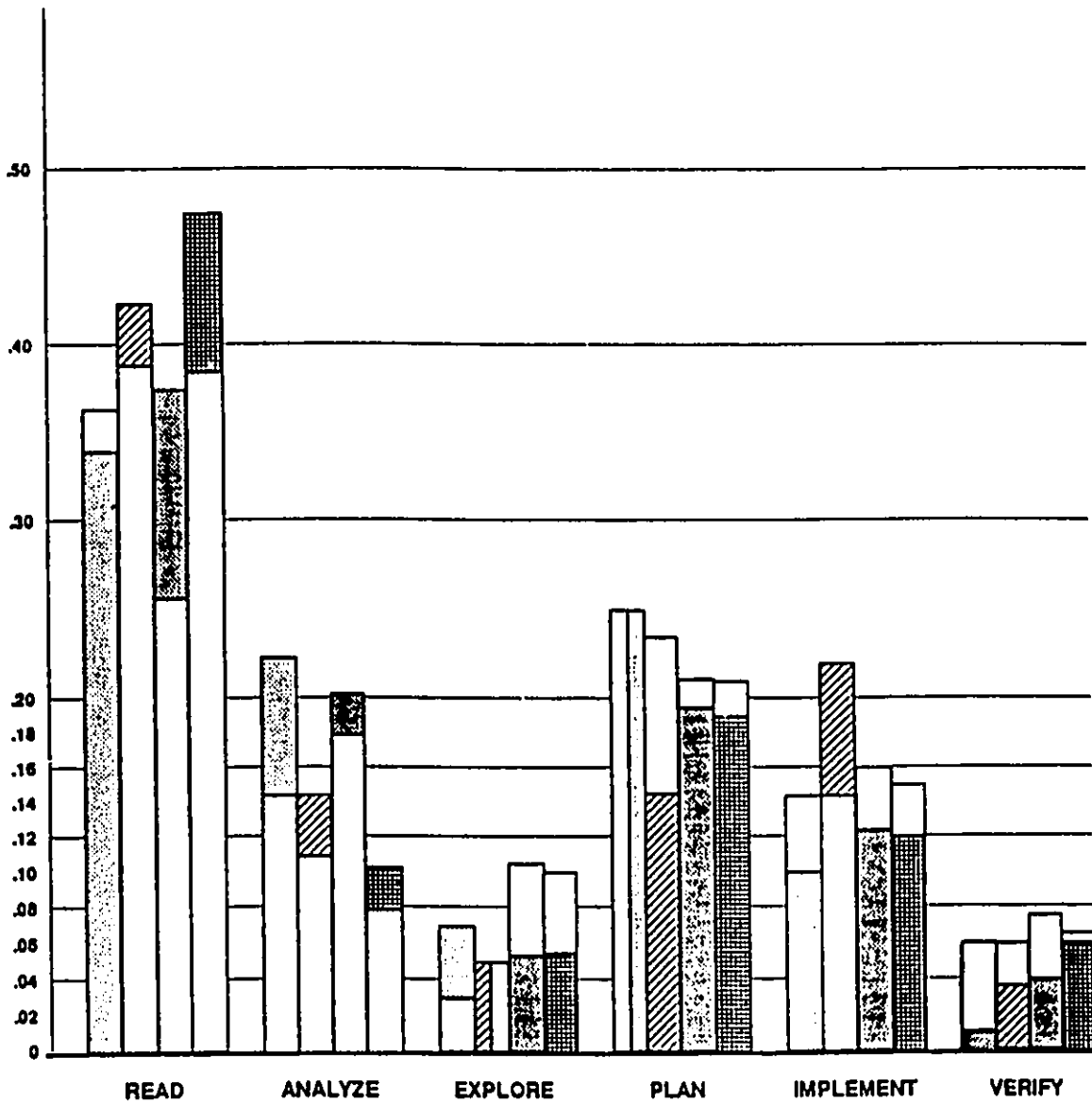
A final note on the nature of these data is the degree to which they represent ill-structured problem solving. By definition, ill-structuredness is relative to the solver, and for this reason, solvers were asked how they experienced the two experimental tasks with regard to the attributes of ill-structured problems. The rating results (Appendix K) demonstrate a strong consensus among solvers that the problems were experienced as ill-structured problems.

## Global Strategy Use

The data source which reflected the actual sequences of strategies used during the solving process was CVP data. As described in chapter three, the CVP data was continuously coded and used to construct CVP maps (Appendix L). Each map consisted of the sequence of strategies applied by a solver as he or she worked on a problem while thinking aloud. In constructing CVP maps, specific strategy codes were placed, in sequence, on a time line depicting the amount of time devoted to each strategy. Strategies belonging to each global strategy were represented in different colours, providing a visual representation of global strategy use. These maps provided not only a characterization of the strategies employed, but a basis for the comparison of relative times devoted to global strategies across expertise, domains and tasks. Furthermore, the construction of CVP maps revealed major patterns of global strategy use.

### Relative Time Devoted to Each Global Strategy

The results summarizing the relative solving time devoted to each global strategy is presented in the form of a bar graph depicting the mean percentage of solving time devoted to each global strategy (Figure 4). The data on which this graph is based are presented in Appendix M, Table M-1. In order to highlight the strongest differences in the relative time devoted to each global strategy, a criterion for identifying the major differences across expertise, domains or tasks was established. This criterion was chosen, based on an analysis of the relative time data for each global strategy, to provide



**FIGURE 4** Bar Graph Representation of the Mean Percentages of Solving Time Devoted to Each Global Strategy

TASK T1 PATTERN     BP     SS     PSP     PSS

TASK T2 WHITE     ALL GROUPS

a single criterion which could be applied to the data across each global category to determine major patterns of difference. Based on this analysis, a difference of 5% or more between any two mean percentages of solving time is considered a major difference, because this degree of variation functioned to select patterns of difference in each global category. A higher degree of variation excluded patterns in less-used global strategy categories and a lower degree of variation failed to discriminate patterns because it included a large number of cases. The presentation of results focuses on the differences which meet this criterion of difference, with weaker patterns included where they are relevant to data interpretation.

Based on the data presented in Figure 4, a number of trends in global strategy use can be determined. These global trends were important because they provided the framework for further analysis. Firstly, Figure 4 illustrates an overall pattern of strategy use which is similar for each group. READ strategies consistently occupied the greatest proportions of solving time (M= 38%), followed by PLAN strategies (M= 21%). ANALYZE (M= 14%) and IMPLEMENT (M= 14%) strategies occupied similar percentages of solving time, but were utilized to a lesser extent than read or plan strategies. The global strategies receiving the least amount of solving time were EXPLORE (M= 6%) and VERIFY (M= 5%) strategies. These broad patterns of global strategy use reflect the demands placed on the solvers of ill-structured tasks. In a situation where the problem conditions or goals are not clearly defined, solvers must devote more time to reading and comprehension of the problem text in order to form an adequate representation of the problem (Voss, 1989). The relatively high proportion of

the time devoted to planning was a reflection of the essential planning nature of the experimental tasks. Somewhat unexpected, however were the relatively small proportions of solving time devoted to EXPLORE and VERIFY strategies. By definition, ill-structured tasks require solvers to bring additional information to the solving process and to deal with uncertainty in their solutions. It might be expected therefore, that more solving time would be devoted to exploring relevant information and evaluating the outcome. Considerably more light will be shed on both expected and unexpected trends in strategy use as the results unfold.

Within these broad trends, global strategy use varied across expertise, domains and tasks. When global strategy use data is analyzed across expertise, a number of patterns emerge. During the reading phase, professors were observed to devote less time than students to READ strategies (Figure 4). These results suggest that there are important differences in the ways that students and professors use READ strategies while solving problems, and this hypothesis will continue to be addressed as the results are elaborated.

Domain of expertise also appeared to affect the percentage of solving time devoted to READ strategies. For biology solvers, Task 1 was a more familiar task, whereas for political science solvers, Task 2 was more familiar. The differences between professors on Task 1 showed that time devoted to READ strategies can be less in familiar domains. This familiarity effect was maintained in cross-task analysis for political science groups. The influence of the familiarity of the problem domain on the relative time spent on READ strategies will be explored further as more results are integrated.

Expertise effects were also observed in the relative time devoted to ANALYZE strategies. Professors consistently devoted more time to ANALYZE strategies than students and, except for biology solvers on Task 2, these differences met the major difference criterion (Figure 4). This finding is consistent with the finding of Voss et al. (1983), that expert problem solvers devote more time to analysis and will be explored more deeply in the analysis of specific ANALYZE strategy knowledge.

The proportion of solving time devoted to EXPLORE strategies was consistent across expertise, but varied more by domain. Domain differences were observed on Task 2, where political science solvers devoted more time to EXPLORE strategies than biology solvers and in contrast, biology professors devoted relatively more time to exploration on Task 1 (Figure 4). These findings raise the question of whether the extent of exploration is related to the depth of knowledge available in a problem domain and this question will be revisited as more data are presented.

Except for biology students on Task 1, the proportions of solving time devoted to PLAN strategies were similar across expertise, and tasks. Three of four major differences identified in the PLAN strategy data (Appendix M, Table M-1) result from the relatively lower proportion of solving time devoted to planning on Task 1 by biology students. During the reading phase, biology students frequently gave verbal indications that they recognized Task 1 as familiar (e.g. "OK... This is an easy problem for me..." (BS-8, 54-55). This perception of familiarity may have resulted in biology students taking less time to plan, believing that the solution was available as prior knowledge. This premise will be explored further in the context of specific strategy knowledge.

The relative time devoted to IMPLEMENT strategies varied more widely for biology solvers than for political science solvers. Across tasks, biology professors devoted proportionately less time to IMPLEMENT strategies on Task 1 than on Task 2, in contrast to biology students who devoted more time to IMPLEMENT strategies on Task 1 (Figure 4). In the context of global PLAN strategy data, this pattern of IMPLEMENT strategy use required further attention in the analysis of specific strategy knowledge.

Except for a disproportionately low use of VERIFY strategies in Task 1 by biology professors, the proportion of solving time devoted to VERIFY strategies was consistently low across expertise, domains and tasks (Figure 4). The proportionately lower time devoted to VERIFY strategies by biology professors on Task 1 suggests a possible expertise effect in that VERIFY strategies are not as strongly evoked when one has expertise in the problem domain. This effect was also borne out in the note-using behaviour of biology professors who used their notes to evaluate the solution of Task 2 more frequently than Task 1 (Appendix J). This interpretation is at variance with the finding of Voss et al. (1983) that solvers with more domain knowledge tend to evaluate more extensively. This variance raises a more general concern for the validity of the generally low levels of verification behaviours observed. Derry and Kellis (1986) reported that checking behaviours often remain covert in CVP situations and may be under-reported relative to other strategies. Both of these issues will be addressed in the exploration of specific strategy knowledge.

### Patterns of Global Strategy Use

The observed trends in global strategy use can be elaborated through the analysis of patterns of global strategy use. The analysis of CVP maps at the global strategy level revealed distinct patterns of strategy use for each global strategy (Table 3). An overview of the results presented in Table 3 reveals that differences in patterns of strategy use occurred more frequently across expertise (16) than across domains (4). These patterns emerged from the data and reflect naturally occurring differences and similarities across CVP maps. Frequency analysis of these patterns across expertise and domains provided insights into the problem solving behaviours of professors and students.

The focus in interpreting this data is on the major differences in pattern use between groups. A major difference in pattern use was defined as a frequency difference of four or more cases between groups, across expertise or domains. This criterion was selected because it highlighted the strongest differences between groups, based on the frequency data. A difference of three cases failed to discriminate patterns across expertise and domains since it included most cases. Conversely, a difference of five or more cases eliminated most potential patterns. The application of this criterion can be illustrated by the interpretation of R1 pattern data from Table 3. Within the domain of biology, 7 professors and 1 student demonstrated an R1 pattern and, in the domain of political science, an R1 pattern was demonstrated by 12 professors and 4 students. In both domains, the difference in the number of cases in which an R1 pattern was used by professors and students exceeded the criterion of four or more cases, and expertise patterns were identified. Across domains, 12 political science professors, compared to 7

Major Patterns of Global Strategy Use in CVP Data

General Characteristics of Global Strategy Patterns	BP (n=18)	BS (n=18)	PSP (n=18)	PSS (n=18)	Pattern(s)	
					E	D
R1 - Single reading, minimum interruption.	7	1	12	4	B; PS	P
R2 - First reading frequently interrupted	3	12	1	5	B, PS	S
R3 - Minimum interruption of first reading, second interrupted reading	8	5	5	9	PS	S
A1 - Predominantly sequential analysis	8	5	7	2	PS	
A2 - predominantly temporally isolated analysis episodes	5	9	6	7	B	
A3 - infrequent (<3) analysis episodes	5	4	5	9	PS	S
E1 - multiple (>3) exploration episodes	3	7	6	6	B	
E2 - one or two exploration episodes	8	4	7	3	B; PS	
E3 - no exploration episodes	7	7	5	9	PS	
P1 - sequences of planning episodes	12	7	11	8	B	
P2 - intermittent planning episodes	2	7	2	5	B	
P3 - infrequent (<3) planning episodes	4	4	5	5		

Table 3

General Characteristics of Global Strategy Patterns	BP (n=18)	BS (n=18)	PSP (n=18)	PSS (n=18)	Pattern(s)	
					E	D
I1 - three or less solution statements with reasons	1	5	3	3	B	
I2 - three or less solutions statements, with no reasons	12	6	11	8	B	
I3 - no solution statement	2	1	1	4		
I4 - multiple (>3) solution statements	3	6	3	3		
V1 - up to 4 verification episodes	10	9	13	12		
V2 - multiple (>4) verification episodes	2	3	1	2		
V3 - no verification episodes	6	6	4	4		

**Note:** Patterns can be discerned when there is a frequency difference of 4 or more cases between groups across expertise (E) or across domains (D)

B = biology    PS = political science    P = professor    S = student

biology professors, demonstrated an R1 pattern. The difference of 5 cases between groups exceeded the criterion of 4 or more, identifying a domain difference for professors. Between students across domains, however, the between-group difference in the number of cases in which an R1 pattern was demonstrated was 3, and did not constitute a pattern of difference, based on the criterion established.

### READ Strategy Patterns

Based on CVP maps, there were three distinct patterns of READ (R) strategy use (Table 3). R1 was characterized by the solver reading the entire problem statement with minimum departure from the text (2 brief episodes or less) and returning infrequently to the text (2 brief episodes or less) while working on the problem. The R1 pattern is exemplified in a map sequence from BP-6, Task 1:

**R:1** - begins reading the problem.

**R:imp** - interrupts reading to note important information.

**R:1** - resumes first reading.

**R:fam** - interrupts reading to note familiarity.

**R:1** - completes first reading.

**A:info** - analyzes given information.

**P:out** - outlines a plan.

**A:per** -analyzes perspective being taken.

**A:sub** - identifies sub-problems.

**A:info** - analyzes information.

**A:per** - analyzes perspective being taken.

**R:re** - re-reads portion of problem text.

**I:soln** - states solution.

**V:eval** - evaluates solution.

Implicit in the R1 pattern of strategy use is that the solver must comprehend the problem and fix in memory all essential information in a single reading. This demand for highly developed R strategies is reflected in the frequency counts for the R1 pattern: professors, and political science professors in particular, exhibited the R1 pattern more frequently than students. This interpretation of the R1 pattern is also supported by the note making behaviour of solvers. The solvers who exhibited an R1 pattern did not, for the most part, make any notes to support their comprehension or representation of the problem (Appendix J).

In contrast, an R2 pattern was more typical of student reading patterns. The R2 pattern was characterized by a first reading which was frequently interrupted in order to note important information, elaborate meaning, analyze information or monitor understanding. Solvers exhibiting this pattern frequently re-read portions of the problem text during solving. A typical example of the R2 pattern is observed in the following sequence from BS-8, Task 1:

**R:1** - begins reading the problem text.

**R:imp** - interrupts reading to note important information.

**R:1** - resumes first reading.

R:imp - interrupts reading to note important information.

R:1 - resumes first reading.

R:imp - interrupts reading to note important information

R:1 - resumes first reading.

R:elab - interrupts reading to elaborate information.

R:1 - resumes first reading.

R:imp - interrupts reading to note important information.

R:1 - resumes first reading.

R:imp - interrupts first reading to note important information.

R:1 - resumes first reading.

R:und - checks understanding of problem text.

R:1 - completes first reading.

R:diff - monitors difficulty of problem.....

Inherent in the R2 pattern is a more explicit effort to comprehend the meaning of the text, to fix important information in memory and to connect the problem with prior knowledge. The R2 pattern was frequently accompanied by writing down or marking important details in the problem text (Appendix J). This pattern occurred more frequently among students and in particular, dominated the reading patterns of biology students.

The R3 pattern reflects an intermediate sequence. In this pattern, the solver reads the entire problem text with minimum interruption, and immediately enters into a second cycle of reading characterized by interruptions similar to those in the R2 pattern. The solver may

also re-read portions of the text during solving. The R3 pattern is exemplified in the following sequence from PSP-7, Task 1:

**R:1** - reads entire problem text without interruption.

**A:per** - analyzes perspective taken.

**R:re** - re-reads portion of problem text.

**R:elab** - elaborates information given.

**R:re** - re-reads portion of problem text.

**R:und** - checks understanding of problem.

**R:re** - re-reads portion of problem text.

**R:elab** -elaborates information given.

**R:re** - re-reads portion of problem text.

**R:imp** - notes important information.

**A: info** - analyzes important information.

**R:re** - re-reads portion of the problem text.

**R: elab** - elaborates information given...

This pattern is similar to R2 in that it is an explicit attempt to understand and represent the problem, but it is much more systematic and focused in that it is conducted in the context of an overview of the problem attained in the first reading. The analysis of solvers' note making supports this interpretation, in that notes were typically made during the re-read, rather than the first reading (R:1) phase. R3 was the pattern most commonly exhibited by

political science students, and in this respect, they differed from both political science professors and biology students. This pattern was also exhibited by biology professors at a similar frequency to R1.

The characterization of these R strategy patterns and the distribution of their frequencies across expertise suggests a meta-pattern of development in R strategy use. These data suggest a progression from the frequently interrupted R2 pattern characteristic of biology students, to the two-cycle R3 pattern typical of political science students and about half of the biology professors, to the single R1 pattern which distinguishes the reading patterns of professors, and political science professors in particular. This analysis indicates that professors have not only developed more efficient R strategies in that they devote less time to the reading phase, but that they also differ from their students in demonstrating more sophisticated patterns of R strategy use. Across domains, political science students exhibited more sophisticated R strategies than biology students. A breakdown of R strategy use patterns across tasks showed that these patterns of strategy use remained stable across tasks, and did not appear to be influenced by the content of the problems. These observations suggest that R strategy differences exist between professors and students in both domains and that the development of expert R strategies is not a linear progression from novice to expert. In addressing the development of R strategy knowledge, the progression noted in reading patterns may facilitate in bridging the gap between the expert and novice reading and comprehension of problems.

ANALYZE Strategy Patterns

The three patterns of ANALYZE (A) strategies evidenced in CVP maps varied across expertise, and, to a lesser extent, domains (Table 3). A1 was characterized by predominantly sequential analysis episodes with systematic analysis of different aspects of the problem. The A1 pattern is exemplified in the following strategy sequence from BP-5, Task 1:

- ... A:info - analyzes given information.
- A:his - analyzes historical patterns in the given information.
- A:info - analyzes given information.
- A:per - analyzes perspective taken.
- A:link - analyzes connections between elements of the problem.
- A:info - analyzes given information.
- A:sub - identifies sub-problems...

Inherent in this sustained pattern was a controlled application of A strategies. This pattern varied across expertise, appearing more often in the CVP maps of professors than students, with a stronger expertise difference in political science.

A2 was characterized by three or more predominantly isolated analysis episodes. This pattern is illustrated by the following sequence of episodes from PSS-9, Task 1:

- ... A:bias - identifies personal biases.
- R:und - checks understanding of the problem.
- R:rep - generates a representation of the problem.
- P:out - outlines a plan.
- A:per - analyzes the perspective taken.
- R:rep - generates a representation of the problem.
- A:info - analyzes information given ...

Implicit in this pattern is a more opportunistic and unfocused application of A strategies. While political science professors and students demonstrated this pattern with similar frequencies, biology students exhibited this pattern more frequently than their professors. A3 was distinguished by infrequent (less than 3) episodes of analysis over the course of solving the problem, reflecting the least sophisticated pattern of analysis. This pattern was demonstrated most frequently by political science students who differed from both political science professors and biology students in their extent of A3 use.

A meta-analysis of the nature of A patterns and the frequencies of their use can be interpreted as a progression from little analysis effort, to intermittent, but more frequent analysis, to sustained sequences of analysis. The expertise differences in A patterns were most pronounced between political science groups, with major differences reflecting more sophisticated use of A patterns by professors. Biology students were similar to biology professors in their use of A3 patterns and tended to use A1 and A2 patterns more frequently than political science students. This interpretation of pattern differences is consistent with

data on the relative time devoted to A strategies reviewed earlier. Both data sources suggest that important strategy knowledge differences exist between professors and students with regard to analysis, and particularly in political science.

The stability of A patterns across tasks was more variable than for READ patterns. A breakdown of A strategy use patterns across tasks showed that, while biology A patterns were stable, political science professors utilized more sustained analysis in a familiar task, whereas political science students demonstrated more extensive analysis in the unfamiliar task. This observation suggests that, while the problem may influence the pattern of A strategy use, that influence may vary between experts and novices.

### EXPLORE Strategy Patterns

The variation in EXPLORE (E) patterns (Table 3) was based on natural groupings in the number of explore episodes in each CVP map. E1 involved more than 3 exploration episodes over the course of solving the problem. While E1 frequencies were similar in political science, biology students engaged in an E1 pattern more frequently than professors on both tasks. This tendency also held across domains, where biology professors were also observed to exhibit an E1 pattern less frequently than political science professors.

E2 involved one or two exploration episodes over the course of solving a problem. The frequencies of this intermediate pattern of exploration varied across expertise, with professors in both domains demonstrating a more frequent E2 pattern. E3 was characterized by an absence of E episodes. This pattern occurred consistently in approximately one-third of the biology solvers' protocols, but political science students engaged in this pattern more

frequently than political science professors.

A meta-analysis of E patterns shows that, in general, professors engaged in E2 patterns (1 or 2 episodes) more frequently than students. With regard to E1 (frequent exploration) and E3 (no exploration) patterns, expertise effects are less clear, with biology students engaging in E1 more often than biology professors but political science students engaging in E3 more often than political science professors. The number of explore episodes does not directly reflect more time on explore strategies, with the relative time data and the pattern data showing little evidence of consistency. Neither do E pattern data reflect the familiarity effect suggested by relative time data, with explore patterns being stable across tasks. Further clarification of exploration strategy knowledge will be sought from other data sources.

#### PLAN Strategy Patterns

The three patterns of PLAN (P) strategies (Table 3) paralleled analysis patterns in that they ranged from infrequent, to intermittent, to sustained sequences of planning strategies. Patterns of infrequent (less than 3) planning episodes (P3) occurred with similar frequencies across expertise and across domains, representing roughly one-quarter of all cases. The other two P patterns varied across expertise. P1 was characterized by sustained sequences of planning episodes. Such a pattern is demonstrated in the following sequence from BP-3, Task 2:

- ... - E:sel - selects information relevant to the problem.
- P:out - outlines a solution plan.
- P:eval - evaluates the solution plan.
- P:diff - monitors difficulty encountered.
- P:mod - modifies the solution plan.
- A:per - analyzes the perspective taken ...

Inherent in the sustained P1 pattern is a controlled application of planning strategies. This pattern occurred most often in the CVP maps of professors, with the stronger expertise differences in biology. The other P pattern which varied across expertise was P2, characterized by multiple (more than 3), but intermittent planning episodes. The P2 pattern was more commonly observed in the CVP maps of students, with the stronger expertise differences in biology. The P2 pattern is exemplified in the following sequence of strategies from BS-2, Task 1:

- ... A:info - analyzes information given.
- P:out - outlines a solution plan.
- R:re - re-reads a portion of the problem text.
- R:und - checks understanding of the problem.
- R:re - re-reads a portion of the problem text.
- A:info - analyzes information given.
- P:out - outlines a solution plan.

E:info - explores available information.

P:out - outlines a solution plan ....

The nature and frequency distribution of the P1 and P2 patterns suggested that P1 reflected the planning of more expert problem solvers. Except for biology students on Task 1, these differences were not reflected in the proportion of time devoted to P strategies, but required more in-depth analysis. A breakdown of strategy use patterns across tasks showed that planning behaviour was stable across tasks for biology professors and political science students, but varied in the remaining two groups, indicating that, at least for some solvers, planning behaviour varies across tasks. The pattern of variation in response to task seems to be also mediated by expertise, however. Biology students exercised more sustained planning in the unfamiliar domain and less planning in the familiar domain. Conversely, political science professors engaged more frequently in sustained planning in the familiar domain, and demonstrated fewer planning episodes in the unfamiliar domain. This analysis indicates that there are not only different planning patterns across expertise, but that planning behaviour may be evoked in response to different conditions of familiarity for professors and students.

### IMPLEMENT Strategy Patterns

There were four IMPLEMENT (I) patterns discerned from the CVP maps, based primarily on the number of episodes identified. The most frequently occurring I pattern, I2, which accounted for 50% of maps, was characterized by three or less solution statements, offered without supporting reasons. The I2 pattern varied across expertise, with biology

professors demonstrating the I2 pattern more frequently than biology students. A similar, but weaker, expertise effect was observed in political science. The I1 pattern, in which solvers provided reasons for their statements was generally less frequent, but demonstrated an expertise effect in biology, with biology students more likely to give reasons than biology professors. Biology students also engaged in multiple solution statements (I4) more frequently than other groups, and demonstrated longer mean solving times for each problem. Inherent in the I4 pattern was an uncertainty about the solution and a reluctance to leave the problem. This interpretation of the I4 pattern is also supported by the observation that biology professors exhibited an I4 pattern more frequently on the unfamiliar task (Task 2). Furthermore, the occurrence of the I4 pattern was more common for biology students on Task 1, and this result is probably related to the short time spent on planning in Task 1 by biology students relative to other groups. The I3 pattern also reflected difficulty in arriving at a solution. The I3 pattern was characterized by failure to make a solution statement. The incidence of I3 was somewhat higher for political science students, due to their failure to state a solution relatively more often than other groups on Task 1. These pattern differences suggest that students were more likely than professors to experience difficulty in stating a solution; that implementation patterns appear to be related to the planning that precedes them; and that unfamiliar tasks are more likely to present implementation difficulties.

### VERIFY Strategy Patterns

The patterns of VERIFY strategy use (Table 3) were stable across expertise, domains and tasks. The most frequent pattern for all groups, accounting for 60% of the CVP maps,

was one in which the solver verifies the solution in up to four verification episodes (V1). A complete absence of verification characterized a further 28% of the maps. This observation reinforced the question raised about the possible under-reporting of verification activity, which will be probed further in RD interview data.

### The Contribution of Strategy Pattern Data

The examination of patterns of global problem solving strategies is described in some detail because it contributed in a unique way to the articulation of the EC strategy knowledge of professors and students. The identification of patterns of strategy use begins to bring plausible explanation to the general trends observed in the relative time devoted to global strategies such as READ and IMPLEMENT. Conversely, trends in global strategy use which appeared similar based on proportion of solving time such as planning, can be differentiated based on patterns of strategy use. With respect to several global strategies, patterns of strategy use which characterized novice, intermediate and expert problem solving could be identified and may serve as points of reference in assessing and remediating strategy use. At a conceptual level, pattern analysis demonstrates that it is not merely whether a strategy is used, or even the relative time devoted to a strategy, which differentiates expert and novice solvers. In addition to these factors, pattern analysis emphasizes the importance of patterns of strategy use when characterizing the EC strategies used during problem solving.

### **Specific Strategy Knowledge**

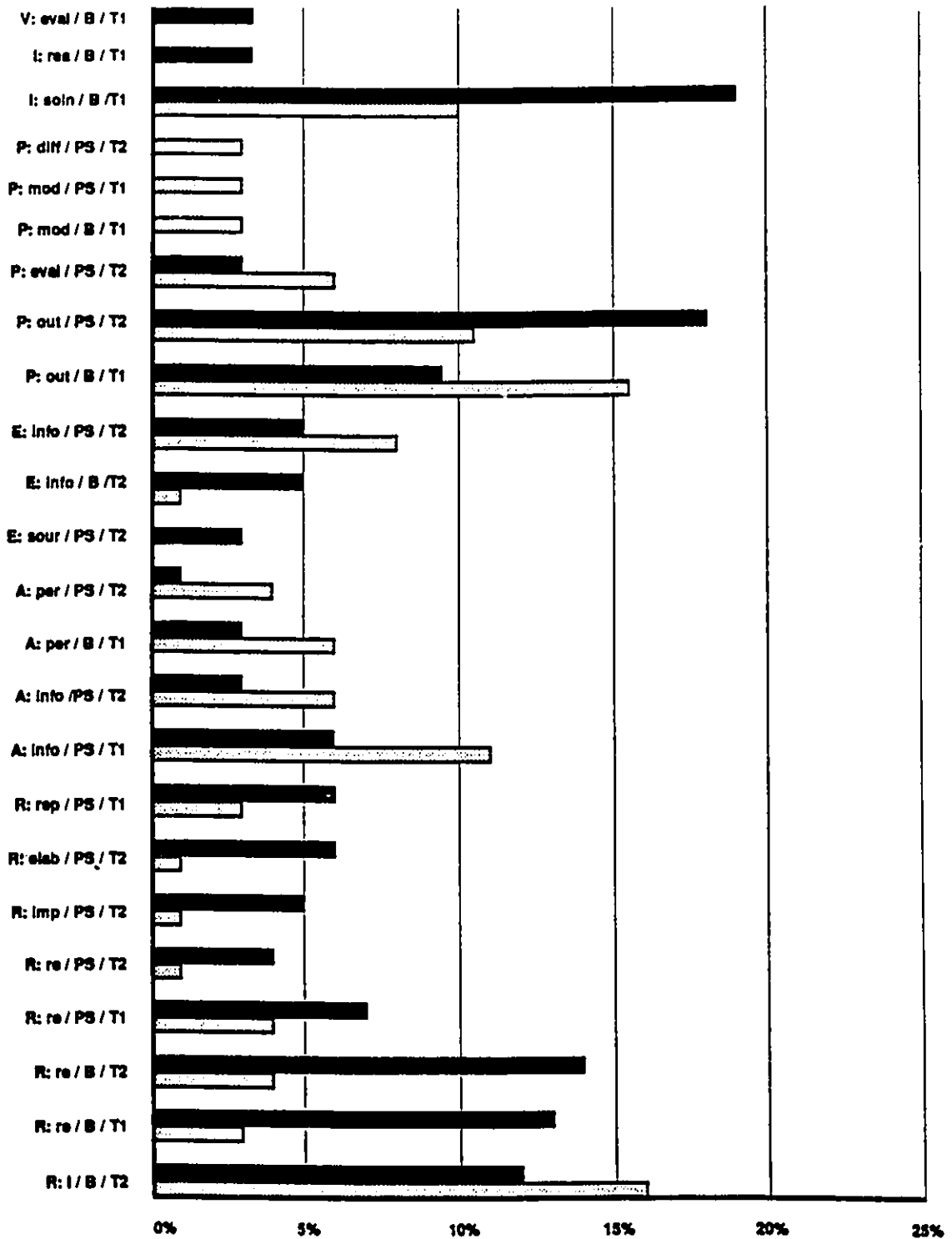
Schoenfeld's characterization of the problem solving process was chosen to frame the analysis of these data precisely because it emphasized the executive control of the problem solving process. It was also the purpose of data analysis to increase the level of detail in articulating EC strategy knowledge by seeking evidence of specific monitoring, directing and evaluating strategies within each of these categories. Consequently, the global framework was expanded, based on the data collected, to include specific EC strategies within each global category. A substantial part of the data analysis process involved a search for evidence of specific strategy knowledge for each of these individual strategies. Specific strategy knowledge is comprised of:

- (1) the procedural knowledge of how to execute each of the specific strategies in one's repertoire;
- (2) the conditional knowledge of when and where to use a strategy, what makes a strategy work, its expected utility, track record and degree of difficulty.

In the presentation and interpretation of specific strategy knowledge data, both forms of this knowledge are integrated. While this integrated approach best fit the data produced by the problem solvers, it necessitates simultaneous consideration of two types of data: the proportion of solving time devoted to specific strategies actually used by the problem solvers and the frequencies of reported conditional knowledge.

### Specific Strategy Data

The in-depth analysis of specific strategies within each global strategy represents a contribution to the research literature in that it produced the detailed level of strategy articulation necessary to support instruction. The analysis of specific strategy knowledge for some thirty-two strategies, however, proved quite complex. Therefore, the results are not presented in their entirety. Rather, the major patterns of difference in specific strategy use across expertise (Figure 5), domains (Figure 6) and tasks (Figure 7) are presented and interpreted in the context of the global strategies observed. The data underlying these results are presented in Appendix M, Tables M-2 - M-5). The criterion for discerning major patterns of difference in relative time devoted to each specific strategy across expertise, domains and tasks was defined as a difference of 3% or more of the total solving time. This degree of variation was chosen, based on the relative time data on specific strategy use, to provide a single criterion which could identify the strongest patterns of difference in specific strategy use across all global categories. This lower limit (relative to global strategies) was chosen because of the smaller proportions of total solving time devoted to each specific strategy. Under these conditions, a lower limit of difference was required to highlight the strongest difference patterns across global categories, while retaining the capacity to discriminate patterns of difference in each global category.

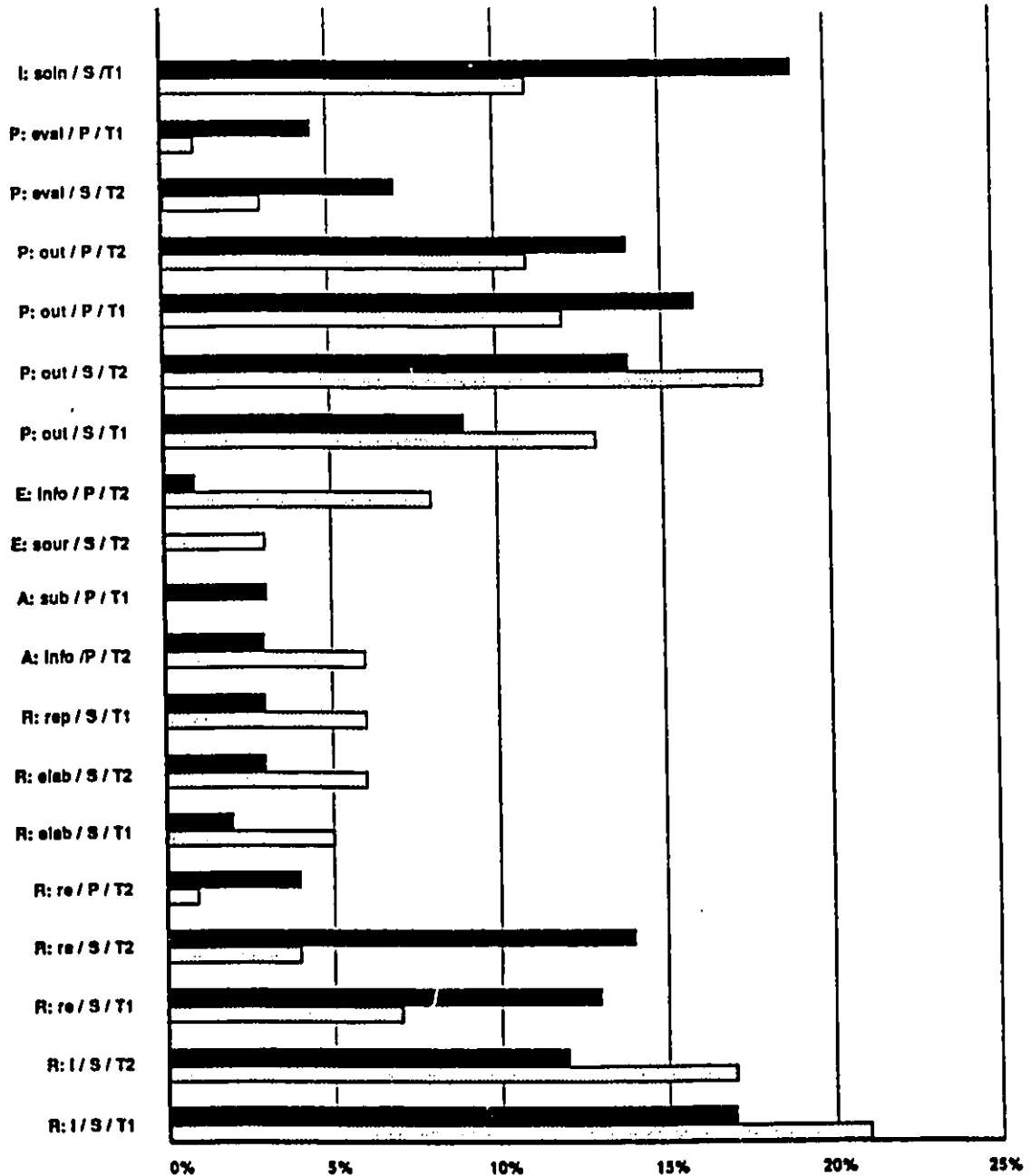


**FIGURE 5.** Bar graph representation of patterns observed in mean percentage of solving time devoted to specific strategies across expertise.

B = biology PS = political science T1 = Task 1 T2 = Task 2

Students Professors

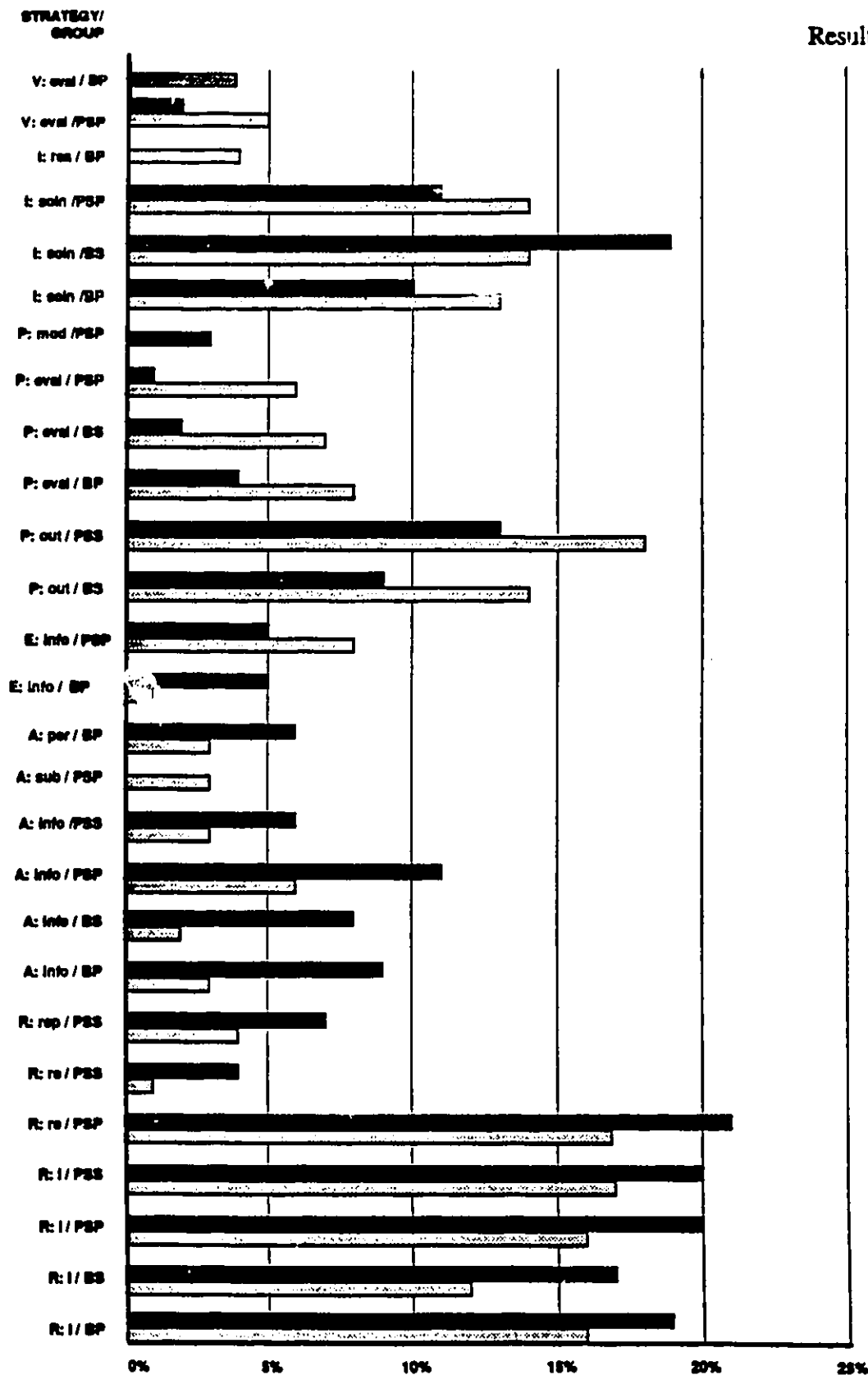
STRATEGY/  
EXPERTISE/TASK



**FIGURE 6:** Bar graph representation of patterns observed in mean percentages of solving time devoted to specific strategies across domains.

S = student      P = professor      T1 = Task 1      T2 = Task 2

■ Biology      □ Political Science



**FIGURE 7.** Bar graph representation of patterns observed in mean percentages of solving time devoted to specific strategies across tasks.

BP= biology professors BS= biology students PSP=political science professors PSS=political science students

Task 1 Task 2

### Conditional Knowledge Data

As described in chapter three, the conditional knowledge data for each specific strategy was based on the number of different items of conditional knowledge reported by each solver. The resulting data (summarized in Appendix G) was analyzed to compare the frequencies of reports across expertise and across domains. The criterion which highlighted the strongest variations in this data was a difference of three or more cases between groups. Based on the data, the selection of 4 or more cases as the criterion of difference would have eliminated many potential patterns. With a difference of two cases, the order of magnitude of difference is questionable in terms of its ability to identify meaningful patterns. The presentation of the conditional knowledge component of specific strategy knowledge focuses on these major patterns of difference, but may include less frequently reported items where they are relevant.

### Specific READ Strategy Knowledge

The analysis of global strategy use (Figure 4) indicated a fundamental difference between students' and professors' use of READ (R) strategies. An analysis of specific R strategy use across expertise (Figure 5) shows that the major contributor to this difference was the more extensive use of the re-read strategy (R:re) by both groups of students. Students' more frequent use of R:re was elaborated by the relevant conditional knowledge reported by solvers (Table 4) in which re-reading was reported to be particularly required when the task was unfamiliar or difficult to understand (conditions more likely to be experienced by students), and functioned both to fix problem details in memory before solving and to verify one's solution with the original statement of the problem. The major

sources of variation in R strategy knowledge between political science professors and students were more wide ranging, and included the more extensive elaboration of the problem text (R:elab), identification of important information (R:imp) and generation of problem representations (R:rep) by students. These strategy use differences are consistent with the more condensed, single cycle of reading which dominated political science professor's reading behaviour (Table 3). These data suggest that students, and political science students in particular, often require more specific R strategies than professors in comprehending and representing problems.

The trend toward more extensive and more explicit use of R strategies by students is especially evident in conditional knowledge data relevant to read strategies (Table 4).

Generally speaking, students were consistently more articulate than their professors in describing when an R strategy was useful and how it functioned (Appendix G, Table G-1). More specifically, the expertise (E) patterns identified in Table 4 show that expertise effects were especially strong with regard to conditional knowledge relevant to re-reading the problem text (R:re), elaborating the problem text (R:elab), identifying important information (R:imp), monitoring interest in the problem (R:int) and generating a problem representation (R: rep). The students' emphases in reporting knowledge relevant to these strategies may reflect the importance of the use of these strategies in their problem solving. This interpretation is also supported by the data on note-making behaviour in which students consistently made notes and marked the problem text during reading more frequently than professors (Appendix J).

Frequencies of Most Commonly Reported Conditional Knowledge  
Items Relevant to READ Strategies

Specific Conditional Knowledge	Group				Pattern(s)	
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	E	D
<b>R:1 - First Reading</b>						
● gives a general overview of the problem	3	3	1	1		
● read slowly to retain information	1	1	0	2		
● identify important information during first read	2	4	1	1		S
● identify important information following first read	3	3	0	2		P
● the problem can be anticipated during first reading	2	2	2	1		
<b>R:re - Re-reading</b>						
● more than one reading of the problem text is necessary	2	1	0	3		
● the amount of re-reading is influenced by familiarity	1	2	1	0		
● re-read text if uncomfortable with comprehension	2	2	0	1		
● re-read to identify and remember important information	4	3	1	5	PS	P
- re-read late in solving to monitor solution	1	2	0	1		
<b>R:imp - Monitor Important Information</b>						
● it is important to identify all relevant information	2	3	1	0		S
● circle or underline important information	3	6	0	4	B, PS	P
● write down important information	1	4	1	2	B	
● numbers and chronological information are important	1	4	0	0	B	S

Table 4

Specific Conditional Knowledge	Group				Pattern(s)	
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	E	D
● actors and their interest are important information	0	0	0	3	PS	S
● the time/effort required is influenced by familiarity	2	4	0	1		S
● highlighting important information helps understanding	0	2	0	2		
● focus on highlighted segments when returning to text	0	4	0	3	B, PS	
<b>R:int - Monitor Interest</b>						
● interest in a problem positively influences effort expended	0	4	5	6	B	P
● real life relevance positively influences effort expended	0	1	3	3		P
● strong personal identification with problem enhances problem solving	0	3	4	4	B	P
● solve problems for extrinsic rewards	1	4	0	2	B	
<b>R:elab - Elaborate Meaning</b>						
● connects problem information with solver's knowledge	0	2	2	2		
● elaboration helps to focus on and remember information	0	1	1	2		
● verbal elaboration is useful	5	9	3	6	B, PS	S
● visual elaboration (imagery) is useful	1	0	4	4		P, S
<b>R:und - Monitor Understanding</b>						
● consciously monitor understanding	0	1	1	2		
● a problem should be coherent and make sense	0	1	1	2		

Table 4

Specific Conditional Knowledge	Group				Pattern(s)	
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	E	D
<b>R:diff - Monitor Difficulty</b>						
● more difficult if the kind of problem is unfamiliar	3	1	1	0		
● more difficult if you lack knowledge in the problem domain	1	3	1	2		
● people problems are more difficult	3	2	0	1		P
● number problems are more difficult	2	0	1	2		
● perceived difficulty influences how a problem is approached	3	1	1	1		
● suspicious if a problem seems too simple	2	1	0	1		
<b>R:fam - Monitor Familiarity</b>						
● familiarity is based on solving similar problems	1	3	2	2		
● familiarity with type of problems provides a solving framework	1	3	0	1		
● familiarity is based on substantive knowledge in an area	2	1	1	0		
● familiar problems are easier to solve	1	3	5	4		P
● more information is available in familiar problems, but they are not necessarily easier to solve	2	0	1	1		
● processing will be more conscious in an unfamiliar context	0	3	2	1	B	
● less comfortable in an unfamiliar context	2	0	2	1		

Table 4

Specific Conditional Knowledge	Group				Pattern(s)	
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	E	D
<b>R:rep - Generate a Problem Representation</b>						
● it is essential to develop a problem representation	2	1	3	3		
● a problem representation reduces the problem text	3	4	0	5	PS	P
● represent the problem in a diagram	3	2	2	2		
● a diagram is more effective in revealing the relationship between problem elements	1	0	3	3		S
● express the problem in your own words	1	2	0	2		
● use underlined/circled words as representation	0	3	0	2	B	
● identify and write down the crux of the problem	3	3	1	4	PS	
● identify the 'big picture' in which the problem fits	2	2	0	1		
● use your own representation of the problem when solving the problem	3	1	1	2		

**Note:** Specific Knowledge Reported is limited to conditional knowledge items reported by 4 or more participants, except in cases where there are 3 reports in total, but they all occur in a single cell.

A pattern is discernable where there is a frequency difference of 3 or more cases between groups across expertise (E) or across domains (D).

P = professor   S = student   B = biology   PS = political science

Within each strategy, expertise patterns in conditional knowledge relevant to R strategies (Table 4) were particularly revealing for the domain of biology. Except for the time they devoted to the re-read strategy, biology students did not show strong patterns of difference with biology professors in the time they devoted to specific R strategies (Figure 5). However, an analysis of conditional knowledge data (Table 4) revealed that biology students differed from biology professors in reported conditional knowledge supporting the identification of important information (R:imp) and monitoring of interest (R:int). For the political science solvers, the expertise patterns in conditional knowledge (Table 4) tended to follow the expertise differences observed in strategy use data (Figure 5).

The analysis of cross-domain (Figure 6) and cross-task (Figure 7) strategy use suggest that expertise is not the only variable which influences R strategy use. For instance, across domains, political science students used elaboration of the problem text (R:elab) for a greater proportion of solving time than biology students and biology students used the re-reading strategy (R:re) for a greater proportion of solving time than political science students (Figure 6). Other domain differences were influenced by the familiarity of the task, with Task 1 evoking more problem representation (R:rep) from political science students and more R:re from political science professors than Task 2 (Figure 7). These trends toward the more explicit strategy use in unfamiliar domains are consistent with the findings of Clement (1982; 1991).

The conditional knowledge data relevant to R strategies (Table 4) also revealed cross-domain patterns in reported items for students and professors. Student patterns were particularly strong for items relevant to identifying important information (R:imp) and the

verbal or visual elaboration of information in the problem text (R:elab). Biology students reported more attention to important information and noticed different types of information than political science students, whereas political science students reported more visual images in elaborating the problem text. Professor patterns of difference were particularly evident in conditional knowledge relevant to monitoring interest (R:int), where political science professors reported the role of interest in problem solving more often than biology professors. These patterns of difference will be revisited in the context of discussions of beliefs held by problem solvers and the types of problems usually solved in each domain.

It is clear from their problem solving performance that professors did not lack R strategy knowledge, but the execution of these strategies among professors was less explicit, particularly in the familiar domain, and the articulation of conditional knowledge associated with strategy use was less fluent (Appendix G, Tables G-1; G-7). For instance, while roughly half of the biology professors made a list of problem components while reading (Appendix J), this strategy for identifying important information was articulated in only one case. On the other hand, even though the reading strategy use of the intermediate level students in this study differed from that of professors, the more explicit performance of students often reflected the attributes of expert solvers. These students showed expert traits in that they spent time comprehending the problem, extracting important information and verbally and visually elaborating the problem (Bransford et al., 1989; Clement, 1991). The condensed and often implicit state of strategy knowledge among experts, together with the more explicit use of a broader range of effective R strategy knowledge by students, suggests that students' R strategy knowledge may be a valuable resource in developing effective EC

strategies relevant to the reading and comprehension of problems.

### Specific ANALYZE Strategy Knowledge

At the global level, professors were observed to devote a greater proportion of solving time to ANALYZE (A) strategies than students (Figure 4), and demonstrated different patterns of analysis behaviour (Table 3). These general findings were consistent with those of other researchers (e.g. Schoenfeld, 1985; Schwartz and Lochhead, 1991) that experts engage in more analysis than novices in problem solving. Beyond this general finding, an analysis of the relative time data for specific A strategies (Figure 5) reveals that one of the major sources of variation is the relatively more extensive use of analysis of given information (A:info) by political science professors relative to political science students on both tasks, reflecting the "systematic scepticism" described by PSP-6 as being essential to political science problem solving. Professors also devoted a greater proportion of solving time to analyzing the perspective taken (A:per) than students when solving problems in their own domains (Figure 5). The concentration of major expertise differences in specific A strategies in political science is consistent with the generally smaller differences between professors and students in biology in time devoted to A strategies.

In addition to expertise differences, the application of A strategies also varied with the familiarity of the domain. Across domains (Figure 6), political science professors devoted relatively more time to analyzing given information (A:info) than biology professors on Task 2, and biology professors devoted relatively more time to identifying sub-problems (A:sub) on Task 1. Specific tasks also evoked different A strategies (Figure 7). Task 1 evoked

more extensive use of A:info across all groups. The stimulus for further analysis of information was quite explicitly expressed as a perception of self-interest on the part of the outfitters. Based on these data, and on the instability of A patterns for political science solvers revealed in a task-breakdown of patterns of strategy use data, the application of A strategies was more susceptible to context effects such as familiarity or specific cues in the text than R strategies.

The exploration of A strategy knowledge was also enhanced by an analysis of conditional knowledge relevant to specific A strategies (Table 5). Across domains, political science solvers reported more conditional knowledge relevant to A strategies than biology solvers, and the differences in conditional knowledge reports reflected the nature of problem solving in the solvers' usual domains. For instance, political science solvers made more frequent reports of conditional knowledge relevant to the analysis of perspective (A:per) and more specifically, reported that (A:per) involved seeing the 'big picture' and considering multiple perspectives more frequently than biology solvers. Political science solvers, and political science professors in particular, made more frequent conditional knowledge reports on restructuring problems (A:rest). Biology solvers, and biology professors in particular, made more frequent conditional knowledge reports about the importance of maintaining objectivity in monitoring bias (A:bias) and A:per. In contrast, political science solvers more frequently reported the role of personal beliefs in problem solving (A:bias). These findings will be revisited in the context of beliefs about problem solving, but reflect fundamental differences in specific instantiations of A strategies between the two domains.

Frequencies of Most Commonly Reported Conditional Knowledge  
Items Relevant to ANALYZE Strategies

Specific Conditional Knowledge	Group				Pattern(s)	
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	E	D
<b>A:info - Critically Analyze Information</b>						
● consider whether problem information is correct/valid	4	1	2	4	B	S
● determine if the information given is complete	6	2	5	0	B, PS	
● carefully dissect given information	2	3	1	5	PS	
● exercise a systematic skepticism	2	0	4	3		S
● weight the importance of factors in the problem	1	3	1	2		
<b>A:bias - Monitor Personal Biases</b>						
● personal views shape how a problem is seen and solved	0	0	8	5	PS	P, S
● recognize personal views but keep them aside	6	2	3	2	B	P
● it is acceptable to use own views in problem solving	0	4	0	3	B, PS	
● own views enhance problem solving	0	3	0	2	B	
● do not let personal views dominate	2	1	2	3		
● personal involvement in a problem increases difficulty	2	3	2	3		
<b>A:per - Monitor Perspective</b>						
● establish perspectives from which the problem is viewed	2	0	3	3		S
● take a broad, "big picture" perspective	0	0	6	3	PS	P, S
● take an objective perspective	6	2	3	2	B	P
● perspective taken is influenced by beliefs	0	0	4	3		P, S

Table 5

Specific Conditional Knowledge	Group				Pattern(s)	
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	E	D
● consider multiple perspectives	0	0	2	4		S
● it requires effort to shift perspectives	0	0	3	1		P
● flexible in shifting perspectives	0	0	0	3	PS	S
<b>A:rest - Restructure the Problem</b>						
● restructure the problem when it doesn't make sense	1	0	6	4		P, S
● restate the problem in more general, abstract terms	1	3	5	0	PS	P, S
<b>A:link - Identify Links Between Problem Elements</b>						
● finding linkages requires conscious effort	1	3	0	3	PS	
● elements of a problem should fit together	1	0	3	1		
● understanding how problem elements interact is important	4	0	2	3	B	S
● writing down or diagramming problem helps reveal links	1	1	2	3		
<b>A:his - Historical Analysis</b>						
● historical analysis can reveal the cause of a problem	2	1	1	3		
● historical analysis can provide solution ideas	2	1	1	3		
<b>A:assm - Monitor Assumptions</b>						
● critically examine the assumptions underlying the problem	2	0	2	0		

**Note:** Specific Knowledge Reported is limited to conditional knowledge items reported by 4 or more participants, except in cases where there are 3 reports in total, but they all occur in a single cell.

A pattern is discernable where there is a frequency difference of 3 or more cases between groups across expertise (E) or across domains (D).

P = professor    S = student    B = biology    PS = political science

Across expertise, strong differences in conditional knowledge about A strategies indicate firstly, that professors are more fluent in articulating their knowledge of A strategies than they are about R strategies (Appendix C, Tables G-2; G-7). Secondly, cross-expertise analysis reveals a wide range of conditional knowledge gaps between professors and students. In contrast to R strategy knowledge, professors are both more explicit in their use of A strategies and more fluent in articulating A strategy knowledge. Therefore, professors' specific A strategy knowledge can provide an effective resource in bridging the gaps observed between students' and professors' specific A strategy knowledge. These data also indicate that attention should be given to domain differences in communicating specific A strategy knowledge.

#### Specific EXPLORE Strategy Knowledge

Analysis of specific EXPLORE (E) strategy knowledge across expertise (Figure 5), domains (Figure 6) and tasks (Figure 7) supports the inference from global strategy analysis that E strategies are knowledge driven. The patterns of difference in specific E strategy knowledge showed that professors operating within their domain of expertise explored information (E:info) for a greater proportion of solving time than when they were working outside of that domain (Figures 6; 7). Political science professors also demonstrated a pattern of difference relative to political science students in devoting relatively more time to E:info on Task 2 (Figure 5). Among students, the influence of expertise in a domain was generally less evident, but a pattern of difference was observed in the higher proportion of solving time devoted to exploring possible sources of

information (E:sour) by political science students working on Task 2 (Figure 6). Each of these patterns suggests that the application of E strategies is mediated by substantive knowledge in a domain.

The conditional knowledge data relevant to specific E strategy knowledge (Table 6) also indicate the mediating influence of domain knowledge on overt E strategy use in that they demonstrate that students' less extensive use of E strategies does not reflect a lack of strategy knowledge. An overview of the conditional knowledge summarized in Table 6 shows that, generally speaking, students reported more conditional knowledge of E strategies than professors (also see Appendix G, Tables G-3; G-7). A strong pattern of difference across expertise for both domains was that students were quite conscious of having to search for relevant information and analogies. In addition to these explicit reports of conditional knowledge, students also demonstrated E strategy knowledge in their retrospective debriefing reports, during which seven students referred to thinking of analogies that were not verbalized in the CVP report. It appears that students may have possessed and used specific E strategy knowledge, but that this strategy knowledge was not reflected in CVP data because appropriate information was not found or reported. This result can be interpreted as support for the premise that explicit demonstration of E strategies is constrained by available knowledge, and that failure to demonstrate E strategies is not solely a function of strategy knowledge. These data suggest that, in the development of E strategy knowledge in students, attention should be given to E strategy knowledge appropriate to the level of knowledge available.

Frequencies of Most Commonly Reported Conditional Knowledge  
Items Relevant to EXPLORE Strategies

Specific Conditional Knowledge Reported	Group				Pattern(s)	
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	E	D
<b>E:info - Explore Relevant Information</b>						
● intentionally search for existing knowledge that will help understand and solve the problem	0	5	3	6	B, P	P
● both academic and personal knowledge are useful	2	4	2	1		S
<b>E:agy - Explore Possible Analogies</b>						
● actively search for useful analogies	0	4	1	4	B, PS	
● analogies can provide a solution framework	0	2	1	3		
<b>E:sour - Explore Possible Sources of Information</b>						
● consult with experts to find information	3	0	3	1	B	

**Note:** Specific Knowledge Reported is limited to conditional knowledge items reported by 4 or more participants, except in cases where there are 3 reports in total, but they all occur in a single cell.

A pattern is discernable where there is a frequency difference of 3 or more cases between groups across expertise (E) or across domains (D).

P = professor    S = student    B = biology    PS = political science

### Specific PLAN Strategy Knowledge

The generally ambiguous characterization of planning activity derived from the relative times devoted to global PLAN (P) strategies (Figure 4) was differentiated somewhat by global pattern analysis (Table 3) and can be further elaborated by specific P strategy knowledge. The major strategy contributing to global planning was outlining a solution plan (P:out), and differences in the proportions of solving time devoted to P:out generally reflect global patterns in which biology students devoted less time to P strategies relative to other groups on Task 1 (Figures 5; 6). One set of READ strategy data contributes to an understanding of the relatively low proportion of planning time of biology students on Task 1. In articulating conditional knowledge about R strategies (Table 4) biology students reported that familiarity provides a problem solving framework and results in less conscious processing more often than biology professors or political science students. Biology students appeared to assess Task 1 quickly and superficially and to utilize less P:out in response to the perceived familiarity of Task 1. This observation is consistent with previous characterizations of novice problem solvers (e.g. Bloom & Broder, 1950; Whimby & Lochhead, 1980).

Aside from this general observation, the P subset of specific strategy knowledge was perhaps the most ambiguous to interpret. The most consistent patterns of difference occurred across tasks (Figure 7). For instance, both groups of students devoted relatively more time to outlining a plan (P:out) on Task 2 and all groups, except political science students, spent more time on evaluating the plan (P:eval) on Task 2. Note making behaviours related to planning also varied by task, with more solvers writing down plan

components and consulting their notes while planning on Task 2 (Appendix J). The task effect persisted across expertise (Figure 5) and domain (Figure 6) differences which frequently held for one task, but not the other. For instance, professors demonstrated more flexibility in planning than students, devoting relatively more time to modifying the plan (P:mod) on Task 1, but not on Task 2. These data, together with the instability of P patterns across tasks for biology students and political science professors, indicate that the task is an important variable in determining P strategy use. The graph summarizing domain differences (Figure 6) also shows that planning is influenced by domain of study, but not in a consistent fashion. Biology professors devoted relatively more time to P:out than political science professors, but political science students devoted relatively more time to P:out than biology students. Based on proportional time data, P strategy use appears to be influenced by the interaction of expertise, domain and task variables.

The analysis of conditional knowledge relative to P strategies elaborated these results (Table 7). An overview of the conditional knowledge data summarized in Table 7 reveals that, generally speaking, political science students made more frequent reports of conditional knowledge relevant to PLAN strategies than either political science professors or biology students. This relatively greater frequency of political science students' reports resulted in most of the cross-expertise and cross-domain differences identified. In contrast, biology students and political science professors (who also showed the least stability in planning patterns across tasks) reported the least conditional knowledge of PLAN strategies (Appendix G, Table G-4). This relative lack of fluency in

Frequencies of Most Commonly Reported Conditional Knowledge  
Items Relevant to PLAN Strategies

Specific Conditional Knowledge Reported	Group				Pattern(s)	
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	E	D
<b>P:out - Outline a Plan</b>						
● problem solving is usually done without planning	0	0	0	3	PS	S
● identify a global goal to guide planning	2	1	2	6	PS	S
● write down the elements of the plan	1	2	0	5	PS	S
● be ordered and systematic in planning	1	2	1	2		
● if familiar, the problem can be solved direct from experience/prior knowledge	3	0	0	1	B	P
<b>P:eval - Evaluate the Plan</b>						
● to avoid getting on the wrong track	2	2	0	3	PS	
● refer back to the problem when planning	3	1	1	1		
● explore the consequences of planning ideas	0	1	1	3		
<b>P:alt - Consider Alternative Plans</b>						
● it is important not to get caught in the first idea that comes to mind	1	0	0	3	PS	S
● requires conscious effort	2	0	1	2		

**Note:** Specific Knowledge Reported is limited to conditional knowledge items reported by 4 or more participants, except in cases where there are a total of 3 reports, but they all occur in a single cell.

A pattern is discernable where there is a frequency difference of 3 or more cases between groups across expertise (E) or across domains (D).

P = professor    S = student    B = biology    PS = political science

articulating specific P strategy knowledge may reflect a more implicit level of planning activity and therefore, less conscious control of the planning process. This interpretation would contribute to an explanation of the task effect for biology students and political science professors and is confirmed in the protocol of PSP-1, who comments on students poor essay planning skills :

"I mean...the problem is that most of us don't know how to do it [describe how to plan] and we are stuck with too many students. So we write something on the plan, but it is not much help the next time... It is so hard to be explicit.... "

(1346-1356).

In short, the utilization of global and specific strategy knowledge relevant to planning follows a pattern consistent with the findings of Brown (1987) that mature planners were more controlled, systematic and demonstrated more flexibility. Within this general pattern, however, planning appears to involve a complex interaction of task, domain, expertise and the level of consciousness at which specific P strategy knowledge is held. These data suggest a complex planning dynamic, but a more detailed characterization of this complexity requires further research. These data also suggest that political science professors may find it more difficult than biology professors to articulate their specific P strategy knowledge to their students, and that further research to characterize expert P strategy knowledge in this domain would support more effective teaching and learning.

### Specific IMPLEMENT Strategy Knowledge

The range of IMPLEMENT (I) strategy knowledge demonstrated in the coding grid (Appendix E) with regard to I strategies was narrow and the strongest patterns of variation were the result of the I behaviours of biology students on Task 1 (Figure 5; 6). The relative time devoted to specific I strategies was similar across groups, except for biology students, who devoted more time to stating a solution and giving reasons for their solution in Task 1 than all other groups. This variation in I behaviour appears to be linked to the proportionately lower planning time demonstrated by biology students on Task 1. As evidence accumulates, it becomes more probable that the biology students' familiarity with the context of Task 1 evoked a superficial planning response. This inadequate planning behaviour, and failure to monitor its adequacy, resulted in more frequent iterative solution statements and longer overall solution times. Based on conditional knowledge data about providing reasons in stating solutions (I:rea) that reasons strengthen and can be used to test a solution (Appendix G, Table G-5), the variations in the use of I:rea across expertise (Figure 5) can also be interpreted in this light. As BS-6 indicates, giving reasons can be a form of confirming a solution as it is being produced: "I figure if I can't rationalize every step then... I may be going wrong somewhere" (350-352). These results show that the utilization of specific I strategies is influenced by the planning behaviour that preceded it and one's confidence with the solution produced.

### Specific VERIFY Strategy Knowledge

The relatively low proportion of solving time devoted to verification was not consistent with previous reports of increased evaluation of solutions (V:eval) (Voss et al., 1983) and consideration of alternative solutions (V:alt) (Schultz & Lochhead, 1991) among experts. This unexpected result focused the analysis of specific VERIFY (V) strategy knowledge to explore possible explanations for this observation. An analysis of verification behaviours evidenced in CVP data revealed that the major source of variation was the relatively greater proportion of solving time devoted to V:eval by professors solving Task 2 compared to Task 1. Apart from this observation, the relative time data were more remarkable for the generally low use of V strategies which they reflected. One explanation, based on the experiences of Derry and Kellis (1987), is that V strategies are more covert in CVP data than other strategies and, consequently, are under-represented in data analysis. With this in mind, the researcher, as part of the retrospective debriefing, asked solvers who did not evidence V strategies if they evaluated their responses, but did not report this activity. In 16 of these 20 cases (Table 3), solvers reported that they were not aware of systematically evaluating their responses. Furthermore, these reports were elaborated with comments which reflected firstly, evaluation at an intuitive "feel good" level in assessing the solution (9 cases) and secondly, the role of problem type on verification behaviour (13 cases).

This elaboration of conditions for strategy use evolved into a reporting of a wide range of conditional knowledge relevant to V strategy use (Appendix G, Table G-6). Although these data, which are summarized in Table 8, reflect relatively few cross-expertise and cross-domain differences, the breadth of strategy knowledge reported indicated that the generally low proportion of solving time devoted to V strategies

Frequencies of Reports of Conditional Knowledge Relevant to  
VERIFY Strategies

Specific Conditional Knowledge	Group				Pattern(s)	
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	E	D
<b>V:eval - Evaluate the Solution</b>						
● it is important to check all solutions	2	2	0	2		
● more likely to evaluate if solution is complex	3	0	0	0	B	P
● more likely to evaluate if there is a specific right answer	2	2	2	2		
● evaluation varies with familiarity of problem	2	0	2	2		
● evaluate by checking solution with the problem text	1	4	1	3	B	
● evaluate reasoning as well as substantive knowledge	1	1	0	5	PS	S
● remain open to change solution	1	2	2	0		
● have difficulty in changing solution	1	2	0	1		
● must have the means or knowledge to evaluate a solution	2	1	1	0		
● evaluates a solution to avoid embarrassment	1	1	2	1		
● a solution should be practical and make sense	1	1	1	2		
<b>V:alt - Consider Alternative Solutions</b>						
● it is important to seek alternative outcomes	2	2	2	3		

**Note:** Specific Knowledge Reported is limited to conditional knowledge items reported by 4 or more participants, except in cases where there are 3 reports in total, but they all occur in a single cell.

A pattern is discernable where there is a frequency difference of 3 or more cases between groups across expertise (E) or across domains (D).

B = biology P = professor PS = political science S = student

demonstrated, not a lack of specific V strategy knowledge, but a relatively small proportion of solving time devoted to V strategy use. This conditional knowledge suggested a second explanation that the ill-structured problems used in this study did not present the conditions which evoke strong V procedures. An analysis of reported conditional knowledge showed that verification is least likely when the task is perceived as having no single correct answer, or being simple or familiar. Solvers were more concerned about verification when the problems were unfamiliar, or had a single correct answer and the failure to get that answer would result in embarrassment. This contrast was also evidenced in the notes made by the researcher during data-collection. Solvers frequently evaluated their responses to the well-structured warm-up problems and demanded feed back on whether they had arrived at the "right" answer. For most solvers, this behaviour was in sharp contrast to their responses to the ill-structured experimental tasks. From the notes made by solvers while generating a solution, it was also observed that biology professors listed the solution components and used those notes in evaluating their solutions more frequently in the unfamiliar context. These results are all consistent with the interpretation that the relatively low proportion of solving time devoted to V strategies appears to be more a function of problem type than lack of strategy knowledge.

Apart from directly influencing verification behaviour, the focus on the "right" answer and avoiding embarrassment in conditional knowledge reported also reflects a performance orientation (ego involvement) in problem solving across groups. Reported conditional knowledge about the difficulty in modifying or rejecting one's solutions

during verification also reflects this posture in university level problem solving. This issue is elaborated by the presentation of data on general strategy knowledge.

### A Summary of Specific Strategy Knowledge Results

In summary, the analysis of global and specific strategy knowledge suggests that there are differences in EC strategy knowledge across expertise and across domains which are particularly important when viewed from an educational perspective. With respect to READ strategies, these data have demonstrated fundamental strategy knowledge differences between professors and students, in that students exercise a broader range of R strategies in more explicit manifestations than professors. Consequently, the strategy knowledge of students is, firstly, more accessible to articulation than the condensed and less conscious knowledge of professors and secondly, more appropriate in facilitating students who experience difficulty in comprehending and representing problems.

With regard to ANALYZE strategies, professors show not only advanced analysis skills but can articulate that knowledge. In contrast, students, and particularly political science students, do not demonstrate the A strategies revealed by their professors and could benefit from explicit instruction in this area. Domain differences observed in the A strategy data indicate that it is important to consider domain-specific applications of A strategy knowledge in designing effective instruction.

The analysis of EXPLORE strategy knowledge indicates that the use of this strategy knowledge is constrained by the depth and organization of prior knowledge .

This finding suggests that it may be productive to further explore specific E strategy knowledge as it applies to different levels of available knowledge.

The analysis of PLAN strategy knowledge revealed a complex interaction among the solver, domain knowledge, and task which cannot be fully characterized based on the data collected in this study. These data do, however, indicate that students are distinct from professors in their patterns of strategy use but that political science professors in particular, may experience difficulty in articulating to students the strategy knowledge necessary to bridge the gap between expert and novice planning.

With respect to IMPLEMENT strategy knowledge it is apparent that implementation behaviour may be, in large part, determined by the planning which precedes it. If planning has been well articulated and evaluated, then implementation is relatively concise and direct. If planning is inadequate, then implementation is uncertain, cyclic and diffuse. The tasks assigned in this study were essentially planning tasks, chosen for their ill-structured character (Yussen, 1985). While these tasks did evoke rich data in other phases of problem solving, implementation involved a summary rather than an implementation of the plan. Therefore, evidence of EC knowledge in the implementation was not as rich as in other areas.

With regard to specific VERIFY strategy knowledge, the actual demonstration of verification strategies was observed to be negatively influenced by the ill-structured nature of the task. The wide range of conditional knowledge reported identified the lack of attention to verification in ill-structured situations and the more general performance orientation of problem solvers as important foci in the instruction of V strategy knowledge.

### **General Strategy Knowledge**

General strategy knowledge is constituted of general beliefs about the problem solving process which mediate the selection, application and modification of strategy knowledge. Participants in the present study reported beliefs relevant to the nature of the problem solving process and self as problem solver; confidence, objectivity and time; and solving problems with others, all of which are forms of general strategy knowledge. The beliefs reported in the next four tables are limited to those reported by four or more solvers, with a full inventory of reported beliefs presented in Appendix H. The presentation of general strategy knowledge data focuses on these more frequently reported beliefs, with less frequently reported beliefs reported where they are relevant.

Beliefs data was generated largely in the retrospective debriefing (RD) portions of the data, in response to general probes by the researcher such as: "Do you like to solve problems?" "Are there situations which influence how you solve a problem?" These data are predominantly solver initiated and therefore reflect what individual solvers saw as important at that moment. Despite this openness, reports demonstrated many common themes. Patterns of difference observed across these common themes are based on the number of different people in each group who reported each belief item. The criterion which highlighted the strongest differences was defined as a difference of three or more reports between groups across expertise or across domains. As with earlier groups of data, this criterion was selected, based on the general strategy knowledge data generated, to provide a single criterion which could be applied to discriminate the strongest patterns

of difference across domains or across expertise for the entire set of general strategy knowledge data. A greater degree of variation would have eliminated most patterns, whereas a lesser degree of variation would fail to discriminate the strongest patterns of difference because it would include a large proportion of cases.

The style of presentation of the final two sets of results shifts somewhat from that previously used. The interpretation of beliefs data required a lower level of inference than in the case of determining the specific strategies used from CVP reports.

Furthermore, the density of beliefs data was lower than the density of data relevant to conditional knowledge. The density and direct use of beliefs data allows the strength and richness of the raw data to best represent the results. These conditions also offer an opportunity to reveal the quality of the data on which previous results are based.

Consequently, the reporting of beliefs data will be framed by the major differences between groups but widely illustrated by excerpts from solvers' protocols.

### Characterization of Process

The ways in which solvers characterized process (Table 9) varied across expertise and domains. The most frequently reported item was that solvers followed a general framework in solving problems. Although reported across groups, this item was most often reported by political science students. These frameworks were most often developed through experience, devised by the solvers themselves, as in the case of PSS-3: "I think my plan is a more systematic thing I do for every problem... That is I read, react, step back, evaluate and conclude." (484-488). Less frequently, more formal

Frequencies of Most Commonly Reported Beliefs Relevant to  
the PROBLEM SOLVING PROCESS and SELF AS PROBLEM SOLVER

Specific Beliefs Reported	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	Pattern(s) E D	
<u>Characterization of Process</u>						
● solve problems following a general framework	3	3	3	6	PS	S
● solving varies between solvers and tasks	2	1	0	1		
● problem solving is a linear process	3	0	0	1	B	P
● problem solving can be unconscious	3	1	0	0		P
● problem solving can be brought under conscious control	2	0	1	1		
● real life solving is different than academic	1	2	3	2		
● real life problem solving adds constraints	0	0	1	3		S
<u>Self as Problem Solver</u>						
● enthusiastic about problem solving	5	3	2	5	PS	P
● does not like solving problems	0	1	1	2		
● gets a kick out of finding a solution	4	1	1	2	B	P
● solves problems primarily for extrinsic rewards	1	4	0	1	B	S
● prefers well structured problems	3	2	0	1		P
● likes ill-structured problems	0	0	1	3		S
● likes logic problems/puzzles	5	0	0	2	B	P
● dislikes logic problems/puzzles	0	0	4	0	PS	P
● does not like math problems	2	0	1	2		
● be organized and careful in thinking	3	3	0	1		P
● desire to do well	2	0	2	2		

**NOTE:** Specific Beliefs Reported are limited to those beliefs reported by four or more participants  
 Patterns can be discerned when there is a frequency difference of three or more cases per group across expertise (E) or domain (D)  
 B = biology P = professors PS = political science S = student

frameworks such as an experimental framework (BP-2; PSP-3), Simon's decision making model (PSS-5) or elements of deBono's lateral thinking program (PSS-6) guided the solvers' general approach to problems.

In contrast to being able to describe a problem solving framework, biology professors reported more frequently than other solvers that problem solving was often an unconscious process. The experience of unconscious processing likely reflects the expert nature of professors' problem solving, but also prevented professors from readily articulating process knowledge. As BP-3 explained, "When I solve problems.. I don't know how most of the time. That's why you are doing your research I am sure.. " (1555-1558). Several other professors (BP-7; BP-9; PSP-4) reported that, while process was usually automatic, it could be consciously evoked when difficulty was experienced or to compensate for known weaknesses. The degree of consciousness at which professors believe they experience their problem solving knowledge has direct consequences for process teaching, as BP-3 confirmed later in his report: "The way I teach students now... based on my own experiences is that I say 'I can't teach you ... you are going to have to get it on your own' .. [ by solving problems]" (1778-1782).

Biology professors also characterized problem solving a linear process more often than other groups, reflecting their expectations for their own problem solving and that of their students. For BP-1, this approach makes problem solving systematic: "Although there are various factors which interact, I tend to look at them one at a time... in ordered fashion... go through what's working right until I come to something that is not working right... Systematic seems to work best.." (1327-1334). Another biology professor who described himself as a linear thinker, demonstrated the same expectations from his

graduate students:

" I have had a graduate student who seemed to make great leaps of faith all the time... You know, he would go from here to there all of a sudden.. I would be working my way along the pathway logically and I would be following .. OK... OK.. How did you get there? And he could not really articulate how he got there... A non-linear thinker." (BP-4, 807-818).

These beliefs about the problem solving process mediate one's problem solving behaviour and the potential to communicate a strategy to others.

#### Self as Problem Solver

Solvers' beliefs about self as problem solver (Table 9) which exhibited strong patterns of differences fell into several pairs of observations. The first pair represented general strategy knowledge which contributes to motivation patterns. Biology professors made the most frequent reports of getting an intrinsic "kick" out of solving a problem. Conversely, it was biology students who most frequently reported solving problems for extrinsic rewards. This contrast is reflected in the following two excerpts:

"... so it's nice sometimes to sort of retreat into an area where you can solve the problem, because you get this nice feeling out of it. ... it didn't really matter if other people appreciated it because you get a lot of satisfaction." (BP-8, 1864-1871).

" ... and if I can get something out of it like a grade , or a job.. then.. Yeah there has to be something in it for me. If there is something in it for me, then I will work harder at it." (BS-2, 1022-1025)

These data show a gap between biology students' and professors' general strategy knowledge which is relevant to the motivation patterns fundamental to problem solving performance.

Although biology professors and political science students reported a general enthusiasm for problem solving more frequently than other groups, this is not to say that their enthusiasm was unqualified or that other solvers were unenthusiastic. Enthusiasm for problem solving was often qualified in ways that reflected domain differences (Table 9). Biology professors reported preferring well-structured problems more frequently than political science professors and conversely, political science students reported preferring ill-structured problems more frequently than biology students. Political science professors were more specific in their qualification, reporting a strong dislike for puzzles or logic problems in contrast to biology professors who reported liking these types of problems. Political science professors often explained their position in a similar vein to PSP-7: "Well, part of what makes me uncomfortable with the dog and dogfood problem [a warm-up problem] is that the problem has no purpose. There is no reason to solve the problem... It is just a test and when you are tested, it makes you feel uncomfortable.. [..] For me it is not important to solve problems just for the test" (836-864) . An interesting item in this group was a reported dislike for math problems which, although it

crossed three groups, was reported exclusively by female solvers.

Apart from the reported dislike of math problems, these patterns are consistent with the nature of problems typically solved in the solvers usual domain. What is more interesting perhaps, is that the beliefs about the nature of problem solving which characterized professors in a domain were not shared by students, and form part of the problem solving knowledge gap between students and professors.

### Confidence

Although confidence is an essential aspect of self as problem solver, the volume of data generated on this theme warrants separate consideration. Unlike the data reflecting problem type preferences, some of the expertise differences reflected in this theme were unexpected (Table 10). Firstly, professors in both domains expressed reduced confidence in the unfamiliar domain, and to a lesser extent, reported avoiding challenges more frequently than students. These belief patterns result not so much from professors perceived ineptitude in unfamiliar domains, as their expertise in a single domain. PSP-9 explains:

"I don't know if I am really that enthusiastic about doing things that are.. I don't know.. new... I mean there is a tremendous incentive, I think, in academia not to get away from what you do. [...] There's a risk you are going to fall flat on your face and that has a cost associated with it obviously in terms of reputation.. [...] This business is so reputational that I think people are so conservative in sticking to something they know how to do well.." (1346-1412).

Table 10

**Frequencies of Most Commonly Reported Beliefs Relevant  
to CONFIDENCE**

Specific Beliefs Reported	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	Pattern(s) E D	
● generally not confident about problem solving	0	2	2	3		
● wants to have the correct solution	3	2	4	2		
● feels bad if solution is incorrect	2	1	1	0		
● less confidence if the problem context is unfamiliar	5	2	3	0	B, PS	
● fears failure	3	0	0	1	B	P
● avoids challenge	2	1	3	1		
● confidence is increased						
a) if you have academic knowledge in the area	0	4	5	0	B, PS	S P
b) if you have hard data to work with	2	0	2	0		
c) if you have experience with similar problem	2	3	2	2		

**Note:** Specific Beliefs Reported are limited to these beliefs reported by 4 or more participants

Patterns can be discerned where there is a frequency difference of three or more cases per group across expertise (E) or across domains (D)

B = biology PS = political science P= professors S = students

Later in her report she referred to this defensive approach as a "success persona" which was characterized by solving problems only in a certain sphere of deep knowledge, using prescribed methods, to produce solutions in which one feels confident. This "persona" was particularly strong among younger academics. A similar concern with previous exposure to an issue among experts was revealed in the research of Voss et al. (1983) and in the finding reported by Schultz and Lochhead (1991) that experts did not like to solve problems outside of their own domains. PSP-8, whose reputation was firmly established demonstrated how these concerns ebb with experience: "I mean, now I know since I am a senior professor I can ask incredibly dumb questions [outside of her domain] and people won't think I am dumb, because I have this legacy of credibility... Now if I asked them twenty years ago...." (523-529). Students, for whom most tasks are unfamiliar, do not suffer from this liability of expertise.

Also somewhat unexpected at first glance, is the more frequent expression of fear of failure by biology professors relative to biology students (Table 10). This terminology is strong and this category is separate from just "feeling bad if you are wrong". The intensity of this belief is illustrated in this frank exposition by BP-3:

"I guess the reason I am uncomfortable [solving in front of someone] is fear of failing... and I talked about your research with my colleagues and this is not just me.... This is common... Maybe, especially when you reach a certain level ... People expect things of you and it becomes a problem. We all solve problems constantly and most of us are pretty good at it, but we are still pretty wary of doing it publicly, because of fear of failure." (1626-1639).

Again, the theme of domain expertise as a liability rather than an asset generalizable to solving problems in other domains emerges. The "success persona" and concerns regarding failure are also reflected in some of the conditional knowledge items reported for VERIFY strategies (Table 8), such as avoiding embarrassment, difficulty in changing or rejecting a solution or requiring sufficient knowledge to judge a solution. Generally speaking, these data raise questions about how the university environment supports the development and practice of problem solving ability, not only for students, but for less experienced faculty as well. More specifically, they demonstrate the challenge posed to nurturing the essential attributes of confidence and risk taking in the university learning context. Professors can hardly communicate to students beliefs they do not possess themselves.

Although solvers tended to report negative views on confidence more often, there were some reports on the factors which build confidence. Solvers across domains drew confidence from having experience with similar problems. Biology students and political science professors reported that having academic knowledge in a problem domain increased confidence. It was professors and not students, however, who reported gaining confidence from having hard data to work with. Despite their emphasis on negative reporting, this last item reflects professors' confidence in being able to solve a problem, given appropriate information.

### Objectivity

Beliefs relevant to objectivity in problem solving (Table 11) show clear patterns of variation across expertise and domains, and have pervasive influences on the problem

Table 11

Frequencies of Most Commonly Reported Beliefs Relevant  
to OBJECTIVITY and TIME

Specific Beliefs Reported	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	Pattern(s)	
					E	D
<b><u>OBJECTIVITY</u></b>						
● personal feelings and experiences motivate and provide input for problem solving	0	3	0	3	B, PS	
● be aware of personal feelings, but don't let them dominate	2	1	2	3		
● keeps personal feelings and experiences aside	6	2	3	1	B	P
● uncomfortable with revealing personal views in problem solving	4	0	1	2	B	P
<b><u>TIME</u></b>						
● insufficient time is a problem	1	3	0	2		
● time constraints cause stress which reduces solving ability	2	5	1	2	B	S
● works within given time constraints	1	0	0	4	PS	S
● needs time to produce the optimum solution	1	1	1	3		
● difficult problems require more time	2	1	0	1		
● it is important to get the right answer fast	0	3	2	0	B	S

**Note:** Specific Beliefs Reported are limited to these beliefs reported by 4 or more participants

Patterns can be discerned where there is a frequency difference of three or more cases per group across expertise (E) or across domains (D)

B = biology P = professors PS = political science S = students

solving process. A survey of the major patterns of objectivity beliefs summarized in Table 11 reflects a continuum of standards of objectivity. On one end of the continuum, the belief that one's own feelings and experiences motivate and add important input to problem solving is reported exclusively by female students in both domains and is reflected in BS-3's account of what motivated her solution:

" From reading this, I don't like hunting. I don't know why men hunt. I can't see any pleasure in killing something. I can't condone that. My first .. [response] as soon as I read that was.. just stop hunting." (881-886).

This student's solution was, in large part, influenced by her feelings about hunting. The next point in the progression is to be aware of personal feelings but not to let them dominate. This view crossed domains and is represented well by PSS-3, who, although she values "first impressions" and gains confidence from having strong feelings on an issue, qualifies the use of such knowledge:

"This one, I would probably be more implicated in it personally.. which means it is difficult to make sure I am looking at all options available. So really, you have to be cautious.. step back. You know.. we had the feely part, now step back and look." (1005-1013).

At the far end of the continuum is the view that personal feelings, values and experiences should be kept aside when solving problems. This perspective was reported

more frequently by biology professors than other groups. This pattern, which suggested a stronger valuing of objectivity by biology professors was also reflected in more frequent biology professor reports of discomfort with having to reveal personal feelings in problem solving (Table 11). More generally, this belief is reflected in the relatively high proportion of positive statements regarding objectivity made by biology professors (14/16) in relation to biology students (2/6), political science professors (5/8) and political science students (3/10) (Appendix H, Table H-3). These beliefs were clearly illustrated by BP-6:

"This is the sort of a problem I can be empathetic with. But, if you are trying to solve a problem, I think you should pull away from personal feelings ... And that is what I did. I did, in fact, mentally pull back ... which is why I mentioned it the very first time ... But I was sort of embarrassed that I immediately began to feel personal about it, ... but I pulled back and tried to be impersonal and just look at the problem very objectively." (242-253).

Among the solvers who minimized the role of personal feeling and experiences in problem solving, this form of objectivity was equated with being scientific: " I am trying to solve it very scientifically, or as objectively as I can, without being influenced by my own personal feelings." (BP-6, 847-850). To a lesser extent among social scientists, this form of objectivity was reported to be valued in solving academic problems. In describing his "style" of problem solving, PSP-5 comments that " our job [as academics] is to basically stand outside of this" (452-453) and later elaborated:

"and because I am at a distance, I don't have a direct personal stake in constructing outcomes. It gives me an opportunity to put things together in ways which I get a lot of satisfaction from... because I believe them to be novel and as close to the truth as one can get..." (1138-1145).

These data reflect the importance of objectivity (as characterized by minimizing the "refraction" of rational processing as it takes place in the human solver) in the problem solving of biology professors, in particular. They also demonstrate that these beliefs have not been effectively communicated to intermediate level students.

These variations in objectivity beliefs can be seen to influence specific conditional strategy knowledge, particularly with regard to how a problem is represented. Some of the pertinent examples include:

- (1) The reporting of the positive influences of personal interest on problem solving (R:int) by biology students (12), political science professors (13) and political science students (15) contrasted with reports from biology professors (1).
- (2) The strong expertise and domain differences in conditional knowledge about the involvement of personal biases in problem solving (A:bias). Students reported the positive influence of personal views more frequently than professors; and political science solvers report being influenced by personal knowledge and views more frequently than biology solvers (Table 5).
- (3) The conditional knowledge relevant to analyzing the perspective taken

(A:per), in which biology professors report seeking an objective perspective in contrast to political science solvers who more frequently report that perspective is influenced by knowledge and beliefs and may be multiple (Table 5).

### Time Constraints in Problem Solving

Relative to other themes which emerged from beliefs data, beliefs relevant to time in problem solving (Table 11) are not on the same scale of importance, but they were especially topical among students. Based on data summarized in Table 11, students more frequently characterized insufficient time as a restraint in problem solving and biology students were particularly affected, reporting that the subsequent stress reduces problem solving ability. Biology students also reported the belief that effective problem solving is represented by fast solutions. This belief was also evidenced by several solvers in the warm-up sessions (e.g. BS-2; PSP-2) who equated fast with "smart" and were conscious of how long they were taking. The negative consequences of such beliefs for self-esteem are illustrated by BS-8, who describes her feelings in an exam period: "And when they finish before you and then you see them go... You think, "Oh my God! I am so stupid! Look at them they are all finished and I am still writing my exam..." (795-799). While it is neither practical nor desirable to allow infinite solving time, it appears biology professors, in particular, could be more cognizant of the beliefs nurtured in the learning experiences of biology students and the effects of time allocation on self-esteem and on the development of a performance-oriented pattern of motivation.

### Solving Problems With Others

A final theme that emerged from the beliefs data was solvers' beliefs about solving problems with others (Table 12). Several aspects of these data showed variation across expertise and domains. As indicated in Table 12, the strongest domain differences in this data set were exhibited in the general posture towards solving problems with others demonstrated by the two groups of professors. Biology professors reported preferring to solve problems alone when working in their own domains of expertise more frequently than political science professors, who, in turn, reported a preference for group problem solving more often than biology professors. (When confronted with problems outside of their own domain of expertise biology professors were similar to political science professors in reporting a readiness to consult with other experts.) These differences are characterized by the following two comments:

"I don't know when the last time would be that I ... Consciously tried to... there was a problem .. and another person an I sat down to ... and it was a problem that neither of us had a prior solution to... and sat down to work on it.." (BP-5, 1320-1326).

" What I am really yearning for here is some sort of interaction... somebody to bounce ideas off... or to.. that's what .. that's the way I like to solve problems." (PSP-4, 447-452).

Table 12

Frequencies of Most Commonly Reported Beliefs Relevant  
to SOLVING PROBLEMS WITH OTHERS

Specific Beliefs Reported	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	Pattern(s)	
					E	D
<u>General</u>						
● problem solving is primarily a solitary activity	6	4	1	3		P
● does not like to solve a problem in front of others	3	2	1	0		
● prefers to solve problems with others	0	1	4	1	PS	P
● willing to solve alone, but then explain solution to others	3	0	0	1	B	P
<u>Effects</u>						
● just verbalizing your thoughts, even if you receive no input from others, is useful	1	0	3	0	PS	
● solving with others broadens and enriches thinking	1	2	5	4		P
<u>Consultation</u>						
● consults experts when solving a problem outside area of expertise	3	0	3	1	B	
● does not readily consult in own area	2	1	1	0		

**Note:** Specific Beliefs Reported are limited to these beliefs reported by 4 or more participants

Patterns can be discerned where there is a frequency difference of three or more cases per group across expertise (E) or across domains (D)

B = biology PS = political science P = professors S = students

As with most contrasts, there are shades of grey. Biology professors did report interacting on problem solving, but this interaction was typically retrospective in nature, such as explaining previous solutions (e.g. BP-3, 1608-1613) or discussing a difficult problem with a colleague (e.g. BP-1, 1190-1194). The contrasting views in these examples influenced the entire set of data on solving with others (Appendix H, Table H-4) with only 6/21 biology professors' reports, as opposed to 24/28 political science professors' reports, reflecting a positive posture towards solving with others.

Across students, who are often constrained by having to solve problems alone in the educational context, the patterns were more similar. Political science students reported that problem solving was a solitary activity more often than their professors, and only one political science student reported a preference for group solving. An overview of positive and negative reports about solving with others (Appendix H, Table H-4) however, shows that students have begun, by pale comparison, to reflect the stronger beliefs of professors in their domains. The solitary problem solving reported among students is of interest from an instructional perspective because solitary problem solving can lead to the entrenchment of weak problem solving knowledge (Anderson, 1987). In contrast, solving with others often results in more extensive analysis and planning, more conscious monitoring of process and evaluation of solutions (Paris & Winograd, 1990).

These results show firstly, that there are fundamental differences in the beliefs about solving problems with others between these two domains and secondly, that in many cases intermediate level students do not share in these beliefs. Inherent in these

domain differences and knowledge gaps are implications for university level teaching. For instance, in biology, the reported reticence of professors to spontaneously solve problems with, or even for, students means that these students' exposure to "real" as opposed to edited, retrospective accounts of problem solving are few. In political science, students do not report the same enthusiasm for group solving as their professors, indicating that, since this belief is important to expert political science problem solving, it may require more explicit attention in the education of political scientists.

Solvers who reported interacting with others also reported secondary effects of that interaction which underline the importance of interaction with others in problem solving. Political science professors reported more frequently than other groups that having to describe a problem or a solution to others, even if you receive no input, enhances the problem solving process. Political science solvers also reported that interaction with others broadened and enriched thinking more often than biology problem solvers. The variation in reports across expertise demonstrates gaps between professor and student knowledge in political science which could be addressed in instruction. These data also suggest the important role of interaction with other solvers, a point which will be revisited when exploring the strategy acquisition component of the results.

### A Summary of General Strategy Knowledge Results

In summary, the beliefs reported by professors and students have been characterized by differences across expertise and domains. Expertise differences, in large part, indicate that there are belief patterns which are fundamental to expert problem

solving such as objectivity beliefs in biology or beliefs relevant to solving with others in political science, which are not demonstrated by student solvers. In this sense, these intermediate level students have acquired knowledge in, but have not been enculturated to, their domain of study. Cross domain analysis indicates that beliefs such as the solitary or gregarious nature of problem solving, while they are not exclusive to specific domains, show strong domain patterns and are relevant to domain-specific efforts to facilitate students in developing their problem solving abilities. At a more general level, the beliefs reported by many solvers reflect a strong concern for performance. This performance orientation (as opposed to a learning orientation) has wide ranging educational implications and will be taken up in the discussion in chapter five.

### **Strategy Acquisition Knowledge**

Strategy acquisition knowledge is the knowledge possessed by solvers which enables strategy knowledge to be acquired and enhanced. Participants in this study were asked to describe the kinds of experiences through which they believed they had acquired their problem solving knowledge. Their responses are summarized in Table 13 and reflect three major themes in solvers' reports of strategy acquisition knowledge: the role of reflection, experience and academic influences. The frequencies reported in Table 13 represent the number of different solvers in each group who reported each item. Based on the data presented in Table 13, a frequency difference of three or more reports between groups across expertise or domains was selected as the criterion which identified

Frequencies of Strategy Acquisition Knowledge Reported

Specific Strategy Acquisition Knowledge Reported	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	Pattern(s)	
					E	D
<u>Reflection</u>						
● a general lack of reflection on process	2	2	0	0		
● reflection on process facilitates the development of strategy knowledge	2	2	4	6		S
● it is difficult to articulate strategy knowledge	4	1	0	3	B, PS	P
● it is difficult to articulate how strategy knowledge was acquired	3	3	3	0	PS	S
<u>Experience</u>						
● strategy knowledge develops with experience	3	3	1	1		
● strategy knowledge was acquired primarily by solving problems	3	4	3	5		
● the solving of personal/social problems was an important experience in acquiring strategy knowledge	4	5	1	7	PS	P
● strategy knowledge was acquired from a varied range of experience	2	0	2	2		
● strategy knowledge acquisition was influenced by family interactions	1	2	2	2		
<u>Academic Influence</u>						
● academic experiences did not positively influence the acquisition of strategy knowledge	0	3	0	1	B	
● strategy knowledge was not explicitly addressed in academic courses	2	3	3	4		
● strategy knowledge was addressed by a few (<3) teachers	2	1	2	2		
● logic and math courses positively influenced strategy knowledge	4	1	0	3	B, PS	P

Table 13

Specific Strategy Acquisition Knowledge Reported	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	Pattern(s)
● strategy knowledge was positively influenced by teaching experience	3	2	2	2	
● discussion with others positively influences strategy knowledge	0	1	2	3	
● strategy knowledge was addressed in a workshop setting	0	2	1	2	
Group Totals	35	35	26	43	

**Note:** Patterns can be discerned when there is a frequency difference of three or more cases across expertise (E) or across domains (D)

B = biology    P = professor    PS = political science    S = student

the strongest patterns of difference. Setting the criterion at a frequency difference of four or more between groups would have eliminated most potential patterns, whereas a frequency difference of two would fail to discriminate the strongest patterns of difference between groups because it would include a large proportion of cases. The patterns of difference identified using this criterion provide one focus of analysis, but in this set of data, similar patterns are of equal note, and formed a second focus. As with the beliefs data, direct quotes from solvers best illustrate the findings and are used extensively.

### Reflection

Reports of the role of reflection in acquiring strategy knowledge revolved around whether strategy knowledge could be easily articulated and if so, whether reflection on the use of this knowledge was important in the acquisition of new executive control (EC) strategy knowledge. Report frequencies show that both strategy knowledge and how it was acquired can be difficult to articulate. Biology professors (who also most frequently reported that problem solving was often unconscious) expressed difficulty in articulating process more frequently than biology students or political science professors. All groups expressed difficulty in articulating how strategy knowledge was acquired, except for political science students, who subsequently produced the largest number of strategy acquisition knowledge statements.

Political science students reported that reflection on and experimenting with one's own strategy knowledge or reflecting on the processes of others was an important element in

the development of strategy knowledge more frequently than biology students. To a lesser extent, this pattern was repeated for professors. In contrast, biology solvers reported a lack of reflection more frequently. The reflective posture of political science students was also borne out in their reports of conditional knowledge relevant to verification, in which political science students reported evaluating the reasoning, as well as the substantive knowledge utilized in problem solving more frequently than other groups (Table 8).

The positive influence of self reflection is characterized by PSS-8:

"I mean... if you decided in going one way and it was a total disaster, you tend not to repeat that again. Even if it wasn't a total disaster, after you are through it, hindsight is always 20/20. You are able to see... 'Well, maybe I shouldn't have done that, that particular time....Next time maybe I will try it a different way.' It is interesting to see what you did and didn't do." (1176-1190).

Similarly, some solvers had studied the processes of others:

" Probably sometimes I do it [study the processes of others] to the detriment of what is going on.... I am too busy looking at the interaction of other people when I probably should be participating in what's going on." (PSS-5, 1482-1488).

In contrast, BS-4 reported that:

" The most I have ever thought about problem solving has been in the last month, since you came to our class... " (1135-1138).

These differences in reflective posture have important implications for the development of EC strategy knowledge. It has been widely reported that reflection on process characterizes the behaviour of successful students and problem solvers (e.g. Champagne et al., 1980; Chi et al., 1988; Smith & Good, 1984; Voss et al., 1983; 1986). The domain differences observed between these groups of students (Table 13) suggest that this issue should receive particular attention in academic courses in biology. These data regarding the role of reflection are elaborated by the analysis of data characterizing learning experiences which follows.

### Experience

When asked what kinds of experiences contributed to the development of their problem solving knowledge, the most frequent first responses were either personal or social experiences:

"well.. I could tell you about my sister... Problem solving with her. She has aphasia, so is learning disabled. [...] But her aphasia made me articulate things I otherwise never would have thought about." (PSS-2, 880-890).

" When I was a child, dealing with my girlfriends.... that really had a fundamental influence on me.... I think about that often today.. how we how we used to go through things and come up with plays, and resolve things on our own.... So that's one experience that's definitely influenced me.... " (PSP-4, 1038-1041).

In a similar vein, interaction in the family situation was also described as important (e.g. PSS-5; PSP-9; BS-4). It was often only with specific probing that information about academic influences was elicited. In the context of the role of reflection in acquiring process knowledge, the spontaneity and strength of these reports are not unexpected, since it is likely that social and personal problems will evoke the most reflection because of their personal importance to the solver.

Solvers also consistently acknowledged that strategy knowledge was acquired by solving problems over a wide range of contexts, rather than explicitly learning about problem solving (Table 13). This perception that strategy knowledge acquisition is a secondary effect of solving problems in a domain is also reflected in the more frequent reports by biology solvers (who also reported being less reflective) that strategy knowledge developed with experience. While these reports that strategy knowledge accumulates somewhat passively as one gains experience in solving problems is consistent with the belief reported by biology solvers that problem solving is often unconscious (Table 9) and with reported difficulties in articulating strategy knowledge, this perception presents a hurdle to effective teaching and learning.

### Academic Influences

The characterization of how the acquisition of strategy knowledge was facilitated in academic contexts elaborated the teaching and learning problem further. At a global level, it was biology students who most frequently reported that their problem solving abilities were not positively influenced by their academic experiences:

"I don't know if school has given me that... a way of solving problems... I am sure it is all of the situations in real life that helped me [...] I am not sure if I only had school, if I would be able to answer these problems correctly..(laughter).."  
(BS-5, 1259-1270).

Other reports elaborated the influence of specific kinds of experiences. Across groups, strategy knowledge had been consistently either not explicitly addressed or addressed in less than 3 course experiences. Only one solver (PSS-8) reported consistent exposure to strategy knowledge in academic courses. These reports are consistent with those which emphasized solving problems, rather than explicit attention to how problems are solved, as a major contributor to strategy knowledge growth. The reports which characterized this lack of explicit attention to the problem solving process were not subtle or ambiguous. BP-4, an experienced professor, commented that: "I have never sat down with someone and discussed problem solving per se.... It is something you pick up as you go along." (1030-1034). Similarly, PSP-1 reported that, over her academic career, ".... certainly never had anybody made it [the problem solving process] explicit... Never.." (1968-1969).

The reports of students currently involved in the university learning experience were similar, as illustrated by BS-6:

"I think I would have to say it [strategy knowledge] is something that I have entirely developed myself, because professors don't spend a lot of time teaching you how to go about it. It is something that you can learn yourself through working at home or

your individual reading.... Through your own frustration, when you are solving a problem..... It is clearly something that I have developed myself." (1564-1575).

When strategy knowledge was explicitly addressed in learning experiences, the consequences were positive and endured. BP-9 reported that she:

"was very lucky in that I have had a number of outstanding teachers who just taught process, thinking and solving... They threw us questions constantly and gave us specimens that were unusual... Constantly gave us data that no one had thought about yet.. I had a lot of tutorials with professors which took me in ... a tremendous debt my whole life... This was thirty years ago, and I am still drawing on that training." (1656-1667).

With regard to reading strategies, PSS-8 described her experiences:

" When professors used to tell us to read the question two or three times, I used to think this is ridiculous. I can read this once and start doing it. If I read it too many times I will forget what I studied ...what I am supposed to answer. [...] I had a law professor especially who kept saying 'You can't get a clear cut solution for a case by reading it once.. I can't do that and I have been a lawyer for x amount of years.' He explained why it was so important and [I realized] ..they are saying that so I will understand the question better." (1279-1318).

The kinds of learning experiences which facilitated the development of these solvers' strategy knowledge stand in sharp contrast to some of the learning experiences reported by students in both domains. The following examples reflect the views of just over one half of the students interviewed:

"This is my third year in university, and, other than my third year courses and one second year course, there hasn't been any problem solving. It has been going home and memorizing as much material as you can. Even essay-wise, you don't have to think about them, just spew back what I have told you. [...] Most of the professors are superb teachers. They can get the material across, but it comes down to a lot of multiple choices." (BS-1, 955-973).

"I feel really bad that I was not challenged [in academic courses] to think. Not that I am a genius or enormously intellectual... I just thought that university was supposed to be the time when you were made to think and things were interesting." (PSS-7, 744-755).

Professors are not unaware of this situation. BP-8 commented that: "a lot of the educational system is training by analogy and factual information. Students learn late that it is not a solid walk of known information." (1563-1568). BP-7 rued the fact that "what we give them now is mostly punctual knowledge that does not shape the mind" (761-763). Professors, even with this knowledge, appear to be strongly bound by conventional teaching practices and institutional constraints.

Some of the learning experiences which positively influenced the acquisition of strategy knowledge were logic or math courses, discussions, and tutoring or teaching others. Math or logic courses were reported as influential primarily by biology professors and political science students. In describing their math or logic experiences, solvers invariably described process in terms of a "method" which they could use both to categorize and solve problems. Process knowledge in these domains, even if it was not made explicit, was more transparent to some solvers.

The two more general learning experiences which had positive results, discussion and teaching others, have broader implications. Students and professors in each domain acknowledged that discussion is useful in developing strategy knowledge, but it was political science solvers who reported actually having such experiences and confirmed their utility. In describing her most valuable experiences, PSS-4 identified:

"professors who posed questions in class and encouraged us to discuss our views .... or problems that we talked about in class... When we had to discuss things, it challenged you to think, .. it broadened my knowledge and how I looked at things."  
(2012-2021).

In contrast, BS-1 reported:

"Class discussion will often bring different things out. Everyone has a different way of thinking and it helps people ... Now, I have never had a class discussion... but I have been in the cafeteria discussing things and you get more knowledge from

different perspectives." (837-845).

Especially important to students who had experienced difficulty were student-student interactions. After two frustrating years, BS-8 discovered that:

" The students explain differently and are more relaxed when you ask them. They are not always busy doing something. [...] It is also important to get other students points of view.. It is up to you to use the information or not. Wrong or right, they say things you didn't think of and maybe it's a good idea to check it out... I learned a lot." (1110-1127).

These examples point to the important role of student-student and student-professor interaction in precipitating reflection on thinking and in developing both strategy knowledge and competence in a domain. Students who had opportunities for such interaction, either formally or informally, reported that interaction with others was an important positive influence in their learning experiences. At least in part, the different level of exposure to discussion in the learning experiences of biology and political science students contribute to explaining the different degrees of reflection on process reported by these two groups.

A different form of such interaction which evoked perhaps the strongest responses with regard to its positive influence on the development of strategy knowledge was the activity of teaching others. The task of having to explain process to others brought strategy knowledge to a level of consciousness where it could be both communicated and enhanced:

" I had always been an A student and had written very well.. But I had written unreflectively. I just cranked it out without knowing how. When I was teaching,... I had to think about it explicitly, ... which improved my own writing.. and I think I learned a great deal more about writing. " (PSP-7, 1015-1020).

Similar reports on the positive effects of teaching experience on the development of process knowledge (e.g. BS-1; BS-7; PSS-2) are consistent with research findings on content learning (e.g. Annis, 1983) and support McKeachie's (1990) advice that students "pay to be a tutor, not to be tutored" (p. 194). Taken together, these results relevant to discussion and teaching others make clear the important role of interaction with others in developing strategy knowledge, but any implications of these results must be considered in the context of confidence and "solving with others" beliefs which constrain the potential for such interaction.

#### A Summary of Strategy Acquisition Knowledge

In summary, the strategy acquisition knowledge reported by these university students and professors firstly, demonstrates the important role of reflection on thinking in developing EC strategy knowledge. The relative lack of reports of such reflection among biology solvers indicates a particular area of concern in designing learning experiences in this domain. Linked to the reported lack of reflection is the fact that solvers in all groups except political science students, reported difficulty in articulating strategy acquisition knowledge because it is not a form of knowledge that has been explicitly developed in their learning

experiences. Secondly, these data reveal a distinct lack of explicit attention to strategy knowledge in university classrooms. The general consistency of these reports across expertise reflects the static nature of university level teaching and learning: the learning experiences of present day students with regard to strategy knowledge does not appear to differ from that experienced by their professors. Thirdly, these data indicate that a more explicit approach, together with more interactive teaching and learning methods, produce the strongest development of all forms of strategy knowledge. Together, these data suggest that more attention to how we represent and use strategy knowledge in the university classroom is required.

The interactions among the different forms of EC strategy knowledge explored in presenting the results of this research and the implications of the knowledge revealed for university teaching are considered in chapter five.

## **CHAPTER 5**

### **A DISCUSSION OF GLOBAL ISSUES**

Throughout this investigation, the objectives have been to explore the nature of EC strategy knowledge among professors and students and to articulate cross-expertise and cross-domain differences in this knowledge at a level of detail sufficient to support instruction. To meet these objectives, a two-tier approach to the interpretation of the results was undertaken: the specific results which could contribute to an empirically-based framework for instruction were presented in chapter four, and the discussion of several global issues also reflected in this data was reserved for chapter five. These global issues emerged when the specific results presented in chapter four were considered in the context of the conceptual framework which guided this exploration of EC strategy knowledge. In particular, these results relate to the dynamic nature of the problem solving process; the nature of EC strategy knowledge; and the importance of motivation patterns to problem solving behaviour. While these themes are important in themselves, they also provide a rich context for considering, in broad overview, the implications of the cross-expertise and cross-domain differences in EC strategy knowledge reflected in the data collected. The discussion of the global issues emanating from this research will, therefore, begin with the elaboration of these general themes and then continue with the broader implications of the specific results presented in chapter four. The chapter concludes with recommendations for future research.

### **The Nature of Human Problem Solving**

While the conceptualization of human problem solving depicted in Figure 1 was derived from a critical review of the problem solving literature, it proved to be an apt characterization of the problem solving processes exhibited by solvers in the present study. Although the focus of analysis was on EC strategy knowledge, it was frequently impossible to isolate the implementation of EC strategies from the constraints of knowledge structures, context variables and task effects. The presentation of results is repeatedly qualified by the apparent interaction between EC strategy knowledge and task, expertise (knowledge) or domain of study (context). At the global strategy use level, for instance, READ strategies generally occupied a greater proportion of solving time for students than for professors. In the unfamiliar context, however, professors consistently demonstrated relatively more time devoted to READ strategies than in the familiar context. Both findings illustrate the influence of knowledge on problem solving behaviour. A task influence was observed for ANALYZE strategy use in that Task 1 consistently evoked a greater proportion of solving time devoted to analysis. Context effects were demonstrated in the relatively low use of VERIFY strategies by all groups in response to the perception that there was no single correct answer and the likelihood of being "wrong" was small.

Similarly, patterns of global strategy use (Table 3) were influenced by knowledge and experience (expertise), particularly in pattern differences between professors and students in READ, ANALYZE and PLAN strategy use. A expertise effect was also

observed across tasks within groups, with some patterns such as PLAN patterns varying for familiar and unfamiliar tasks. The domain of study (context) appeared to influence patterns of strategy use, particularly for students in patterns of READ and ANALYZE strategy use. The mediation of the problem solving process by knowledge and experience, personal and situational contexts, and the task at hand was further manifested in the analysis of specific strategy knowledge where the results are summarized by differences in specific strategy use across expertise, domains and tasks.

Especially strong context effects were seen in the exploration of beliefs relevant to problem solving. Beliefs such as those relevant to objectivity were observed to affect the implementation of individual EC strategies, while other beliefs such as those relating to confidence pervaded solvers' overall posture towards the solving process. Throughout these data, the constraints identified in the conceptualization of the problem solving process in Figure 1 were observed to individually interact with EC strategy knowledge. Furthermore, the dynamic and complex interactions of these constraints often made it difficult to isolate the effects of specific EC strategy knowledge. Perhaps the strongest case in this point is the complex dynamic among these constraints which emerged from the analysis of specific PLAN strategy knowledge.

This step back from the specific details of strategy knowledge explored in chapter four reveals the complex and dynamic nature of human problem solving as it was demonstrated by solvers in this study. While the human information processing system certainly places a primary constraint on problem solving behaviour, the influence of EC strategy use, knowledge structures, personal and situational context variables and the

nature of the task were found to be essential and interacting attributes of human problem solving.

### **Characterizing EC Strategy Knowledge**

Within the complex dynamic of human problem solving, the primary focus in the present study was on EC strategy knowledge. Based on existing research on strategy use and instruction, a conceptualization of strategy knowledge proposed by Pressley and his colleagues (Borkowski et al., 1990; Pressley et al., 1985; 1987) was selected as a guiding framework for the collection and interpretation of data. An extensive review of the literature indicated that the adopted framework had not previously been applied to the investigation of university level problem solving, but it provided a strong perspective from which to explore the EC strategy knowledge of professors and students. The results presented in chapter four provide evidence to support the interaction of general strategy knowledge, specific strategy knowledge and strategy acquisition knowledge in determining the selection and application of EC strategies during problem solving.

General strategy knowledge, including beliefs about self as problem solver, confidence, objectivity and solving problems with others permeated the selection, application and articulation of specific strategy knowledge in the course of solving the two experimental tasks and was reflected in the strategy acquisition knowledge reported. For example, the positive objectivity beliefs reported by biology professors were reflected in their strategy use and in the conditional knowledge they reported relevant to

monitoring personal biases (A:bias), identifying the perspective taken (A:per) and monitoring interest (R:int). In contrast, solvers who reported valuing personal feelings and experiences in problem solving reported conditional knowledge relevant to A:bias, A:per and R:int which was consistent with these beliefs. General strategy knowledge relevant to confidence was also evidenced across specific strategy knowledge.

Professors' reports of reduced confidence in unfamiliar domains are reflected in more extensive use of READ strategies under these conditions. Perhaps most evident was the role of confidence beliefs in determining VERIFY strategy use. Verification strategies were most strongly evoked when confidence was threatened by unfamiliarity, or the knowledge of a single correct response. Although not an exhaustive list, these examples demonstrate the importance of general strategy knowledge in EC strategy use.

General strategy knowledge also influenced strategy acquisition knowledge. A pertinent example of this influence is seen in the role of beliefs about solving problems with others on the acquisition of strategy knowledge. In political science, where professors reported more gregarious problem solving experiences, solvers more frequently reported the positive influence of discussion and reflection prompted by discussion on both the outcomes of problem solving and the development of problem solving knowledge. In contrast, negative beliefs about solving problems with others can be seen to contribute to domain differences in these aspects of strategy acquisition knowledge. Biology solvers more frequently reported reservations about solving problems with others and less frequently reported the positive effects of discussion or reflection on process. Furthermore, biology professors reported that problem solving was

unconscious and expressed difficulty in articulating process more often than either biology students or political science professors. Collectively, these results suggest that these beliefs influence the ability of professors and students to be explicit about the problem solving process in a classroom setting and consequently, constrain the development of strategy acquisition knowledge.

The interactions between specific strategy knowledge and strategy acquisition knowledge were less obvious, because of the low level of strategy acquisition knowledge reported by these solvers. Reports of strategy acquisition knowledge were dominated by a lack of explicit attention to process in academic courses and, particularly among biology solvers, were often characterized by a lack of personal reflection on the problem solving process. These conditions limited the number of positive strategy acquisition knowledge reports generated, and in turn, the opportunities for observing strategy knowledge interaction. Among solvers who did report positive strategy acquisition knowledge (e.g. BP-8; PSS-4; PSS-5; PSS-8), there was evidence that solvers who reflected on process and had the strategy acquisition knowledge to monitor, compare and evaluate strategy use experienced the conscious acquisition of specific strategy knowledge. The active consideration of specific strategy use, in turn, contributed to the development of solvers' knowledge of how strategies were related and how strategy knowledge was organized.

A critical assessment of these results from the perspective of the Pressley model of strategy knowledge indicates not only that the three major components of strategy knowledge are present in the EC strategy knowledge of professors and students, but that

these components form an interactive whole in determining effective EC strategy use. Therefore, it is essential that all three forms of EC strategy knowledge be included when characterizing the knowledge necessary for EC strategy use and in the design of instruction intended to develop this knowledge.

A second aspect of the nature of EC strategy knowledge which is mentioned only in passing in the results, but that is relevant to the discussion of the nature of EC strategy knowledge, is the frequency with which solvers reported EC strategy knowledge "of cognition" which they did not use in "regulating cognition". In particular, solvers across groups consistently reported the value to problem solving of generating alternative solutions before making a final solution statement, but only three of the nine solvers who reported this conditional knowledge actually acted on it. Similarly, BS-3 reported using a trial and error approach to problem solving, even though she knew it was inefficient. BS-4 and BS-9 acknowledged that they had been given READ strategy advice that they had chosen not to follow. PSP-4 reported the importance of focusing her EXPLORE strategies, but then explained that in her own problem solving, she frequently experienced difficulty because she failed to follow her own advice. Conversely, professors were especially likely to use strategy knowledge which they did not articulate when they were asked to describe their thinking. This was particularly true for READ and PLAN strategies.

These phenomena of acknowledging the potential of EC strategy knowledge but not using it in problem solving (Salatas & Flavell, 1976) and using, but not reporting specific EC strategy knowledge (Flavell, Beach & Chinsky, 1966) have contributed to

persistent conceptual and methodological problems in metacognition research (Meichenbaum et al., 1985). However, the results of the present research, together with research on strategy instruction, suggest that these phenomena are not the product of an inherent conceptual weakness, but a reflection of the very nature of metacognitive knowledge. In the cases where solvers reported knowledge of cognition which they did not use in regulating their cognition, they were aware of this gap. As in their use of other forms of knowledge, solvers either fail to access or disregard EC strategy knowledge that may be relevant to the task at hand. In the problem solving context, the selection and application of strategy knowledge has been demonstrated to be mediated by knowledge and experience, personal and situational contexts, and the nature of the task. These gaps between knowledge of cognition and knowledge regulating cognition, present a fundamental hurdle in the effective implementation of EC strategy knowledge, but do not render inadequate the concept of EC strategy knowledge.

### **Patterns of Motivation**

Of particular concern to some researchers in university level problem solving research (McKeachie et al., 1986; Nickerson, 1991; Pintrich, 1988a) is the lack of attention to motivation patterns in investigating competent performance in academic domains. The results presented in chapter four are particularly relevant to this concern. Across the components of strategy knowledge and for all groups of solvers, the theme of a performance-goal pattern of motivation (Dweck, 1986; 1989) repeatedly surfaces. As

described in chapter two, solvers who demonstrate a performance-goal orientation to problem solving are more concerned with **demonstrating** competence than **developing** competence. A high degree of ego-involvement in problem solving (Nicholls, 1989) is associated with a defensive behaviour pattern characterized by validating competence, avoiding risk, perceiving competition in cognitive tasks, having rigid (and usually external) standards of performance and perceiving obstacles in problem solving as negative. In short, this pattern of problem solving behaviour parallels the problem solving posture exhibited by many of the solvers in the present study. A performance-goal pattern of motivation was demonstrated in the warm-up sessions by solvers' primary concerns for fast and accurate solutions; in verification, which was strongly influenced by whether there was a single correct response; and was widely reflected in confidence beliefs. A strong learning-goal pattern, characterized by concern for developing competence and acceptance of risk, was reflected in only one protocol (BS-7).

This strong ego-involvement in the problem solving process has important implications for the teaching and learning of EC strategy knowledge. Firstly, patterns of beliefs which contribute to a performance-goal posture in problem solving result in a reticence on the part of professors (and biology professors in particular) to solve problems with or for students. This reticence seriously constrains the degree to which EC strategy knowledge can become more explicit in academic courses. Secondly, there is the general observation that professors, whose primary teaching resource in developing EC strategy knowledge in their students is their own EC strategy knowledge, are most likely to teach students the general strategy knowledge which they possess. In this

investigation, beliefs which contribute to performance-goal (rather than learning-goal) motivated problem solving dominated professors' reports. These belief patterns would not facilitate the acquisition and use of effective EC strategy knowledge by students.

Although patterns of motivation in university level problem solving have not been widely studied, the strong ego-involvement described by PSP-9 as a "success persona" has been described outside the confines of the present research. In characterizing the psychology of science, Maslow (1966) distinguishes between the practice of a self-actualizing, "problem-centred" science from the practice of a more defensive, "ego-centred" science. Maslow described ego-centred science as "defensive, deficiency motivated, safety-need motivated, moved largely by anxiety [created by being confronted by the unfamiliar] and behaving in such a way to allay it." (pp. 22-23). Based on research findings, Maslow contended that, when one's first priority is for self-esteem, the world of knowledge experienced is narrowed, process is defined by static and carefully ordered criteria, and challenge is avoided. These consequences of ego-centred science closely resemble the beliefs reported by professors in both domains, and by less experienced professors in particular. In contrast, problem-centred science parallels a learning-goal pattern of motivation, which would support the development of EC strategy knowledge. Taken in this broader context, the defensive posture towards problem solving demonstrated by solvers in this study becomes relevant not only to effective teaching and learning, but to other scholarly activities as well. The results of this study provoke the broader question of whether the beliefs about problem solving nurtured in the university environment facilitate student learning or the scholarly activities of professors, including

teaching, when the first priority is to demonstrate, rather than develop, competence. In this respect, the general strategy knowledge reported by professors and students contributes to an understanding of some of the difficulties experienced in implementing well-intended teaching strategies at the university level and secondly, brings a new sensitivity for the context in which the development of EC strategy knowledge takes place in academic courses.

### **The Results in Overview**

#### **Expertise Differences in EC Strategy Knowledge**

The results presented in chapter four illustrate gaps in EC strategy knowledge between professors and intermediate level students which identify potential foci for instruction that cross each of the global strategies and the different components of EC strategy knowledge. For some of these gaps, the strategy knowledge of professors appears to provide an effective resource in developing that same knowledge in their students. The results obtained for ANALYZE strategy knowledge and various aspects of general strategy knowledge, in particular, fit this category.

There are areas of EC strategy knowledge where gaps between students' and professors' strategy knowledge are wide (e.g. READ strategies), or in which strategy use is extensively mediated by domain knowledge (e.g. EXPLORE strategies). Under these conditions, the development of student's EC strategy knowledge may not be as straight forward as explicitly teaching expert strategy knowledge to students. The depth of

analysis undertaken in this investigation, together with the selection of intermediate level students to the sample, produced results which support the premise that the development of EC strategy knowledge may not be a linear transition from novice to expert (Dreyfus & Dreyfus, 1986; Peverly, 1991). The phenomenon of intermediate phases of expertise was clearly demonstrated in the READ strategy knowledge reported by experts, intermediate level solvers and students who showed novice patterns. In comprehending a problem, students generally devoted more time to READ strategies than professors. Students demonstrated more explicit attention to extracting important information, elaborating given information, and forming a problem representation during the reading phase. Students could also articulate more conditional knowledge relevant to READ strategies than professors. While effective student READ strategy patterns did not often resemble the professors who demonstrated an efficient, single-cycle reading pattern (R1) in which READ strategy knowledge was exercised in a highly condensed form and was difficult to articulate, students were not non-expert in their reading strategies. In particular, students (and professors) who exhibited a two-cycle pattern of READ strategy use (R3) demonstrated expert attributes in attending to, extracting and relating problem information to prior knowledge in a systematic and focused way. Although the expert READ strategy pattern of many professors may provide a long-term goal for instruction, this strategy knowledge is firstly, deeply internalized and difficult for professors to articulate and secondly, not representative of a model that is easily accessed by students who have difficulty in comprehending and representing problems. The intermediate patterns of READ strategy knowledge provide a progression of strategy knowledge which

is more readily articulated and accessible to novices. This intermediate knowledge can be used to mediate the considerable leap to expert patterns of READ strategy knowledge, by bridging the gap between novice and expert performance with successively more complex READ strategy knowledge. The progression in strategy knowledge supporting effective READ strategies in these results suggests, firstly, that there are discrete intermediate phases in the transition from novice to expert with respect to at least some aspects of the problem solving process and secondly, that the strategy knowledge of the effective student problem solver is an important component in developing models of strategy knowledge to support instruction.

The attention to intermediate levels of strategy knowledge does not, in any way, diminish the value of expert-novice differences in establishing a framework for identifying those areas of EC strategy knowledge which require attention in academic courses or in providing models for some of the strategy knowledge to be learned. Such an emphasis does, however, provide for the effective bridging of wide gaps between novice student and expert teacher, to facilitate more effective instruction. These results imply that, in both research and teaching, we need to give more attention to the strategy knowledge of intermediate level solvers. From a research perspective, the articulation of intermediate levels of strategy knowledge would contribute to our understanding of the development of expertise and to the construction of empirically-based strategy knowledge models which can effectively support strategy instruction. From a classroom perspective, these results underline the importance of student input in the development of strategy knowledge. The articulation of student strategy knowledge not only identifies areas in

which instruction would be profitable, but can provide a well-articulated and accessible strategy knowledge resource for students who experience difficulty. Teaching faculty would be wise to draw on both their own strategy knowledge and the strategy knowledge of successful student solvers in constructing empirically-based models of strategy knowledge in their domains.

### Domain Differences in EC Strategy Knowledge

The domain differences identified in the analysis of EC strategy knowledge demonstrated by solvers in this study prompt a consideration of the extent of domain specificity in EC strategy knowledge. The results in chapter four demonstrate two different levels of domain effects. A primary domain effect is observed in general strategy knowledge. Two illustrative cases are provided by biology professors' strong positive beliefs about objectivity and political science professors' strong beliefs about solving with others. Each of these belief patterns is consistent with (1) the type of problem typically solved and (2) the ways knowledge is generated and tested in each domain. In political science, problems are typically worked on in an ill-structured form, where there are many open constraints and few definitive "correct" answers (Voss, 1989). The generation of an acceptable solution is often founded on argumentation rather than empirical evidence, and the value of a solution is in its acceptance in the problem solving community (Voss & Post, 1988). In this type of problem solving context, multiple perspectives and inputs contribute positively to the closing of constraints, the construction of arguments and the acceptance of the solution. In biology,

experimentation is the primary way of generating and testing knowledge (Tweney, 1991).

In this context, the rigorously controlled manipulation of selected variables to produce reproducible empirical results characterizes much of the problem solving in the domain. Consequently, problems must be well-structured before one can proceed. While this kind of problem solving can be effectively accomplished by teams of researchers, it readily lends itself to solitary problem solving efforts.

A secondary domain effect is seen in EC strategy knowledge across global strategies. At this level of analysis, the domain effect is more subtle, but still largely a function of the type of problem solving which dominates in each domain. Despite fundamental differences in general strategy knowledge, all solvers demonstrated the six global strategies in their problem solving and shared in many of the specific EC strategies. The domain differences occurred in the specific instantiations of strategies and in the reported conditional knowledge which supported strategy use. For instance, solvers across groups monitored for important information when reading the problem text (R:imp), but biology solvers reported recognizing numerical or chronological information as important, while political science solvers reported focusing on actors and their interests. Political science professors reached for multiple perspectives and "the big picture" in identifying the perspective taken (A:per), whereas biology professors sought an objective perspective. While solvers across groups evaluated their solutions (V:eval), political science students reported evaluating the reasoning of a solution (as opposed to only the outcome) more frequently than their biology peers. Each of these examples

illustrates more subtle differences within specific instantiations of strategy knowledge which are consistent with the character of problem solving in the respective domains.

These results indicate that the primary domain-specificity effect in EC strategy knowledge was demonstrated in the beliefs that constitute general strategy knowledge. The different belief patterns demonstrated by expert solvers in each domain appear to be a function of how knowledge is generated and tested in each domain. These different belief patterns influence, but do not radically change, EC strategy implementation. The fundamental strategies for monitoring, directing and evaluating each stage of the problem solving process applied in both domains, but with different emphases in specific instantiation and function, and supported by different conditional knowledge.

These results support the "general strategy" character of EC strategy knowledge and demonstrate the utility of EC strategies across domains. There are, however, important domain-specific aspects of EC strategy knowledge at the general strategy knowledge level and more subtle variations in specific strategy knowledge which are important constituents of the body of knowledge necessary for competent performance in a domain. From the perspective of classroom teaching, these results suggest that students across domains would benefit from the development of all components of their EC strategy knowledge. Within this instruction, however, careful attention should be paid to domain-specific general strategy knowledge and the more subtle forms of specific strategy knowledge. From a research perspective, these results demonstrate that when analysis goes beyond global strategy use to embrace either the breadth of strategy knowledge of the Pressley model or the depth of analysis of the coding grid, a more detailed

articulation of domain influence on EC strategy knowledge can be achieved. This specification of domain differences can contribute to the clarification of the degree of domain-generalness of EC strategy knowledge.

### **Future Research Considerations**

As an exploratory study designed to characterize the nature of EC strategy knowledge in university level problem solving, the present investigation pursued an unusually wide range of strategy knowledge at a considerable level of detail. It is not unexpected, then, that the results reported here have opened several avenues of research. Firstly, there are the questions prompted by the results presented for each global strategy. Although the conditions and the tasks chosen for the present study evoked rich READ and ANALYZE strategy knowledge across forms of strategy knowledge, the analysis of EC strategy knowledge for other global strategies requires further elaboration. How does expertise in a domain influence the implementation of EXPLORE strategy knowledge? Can the complex planning dynamic which seemed to characterize the planning of solvers in this study be further elaborated? What kinds of tasks would be required to evoke a fuller range of IMPLEMENT and VERIFY strategies? How can the strategy knowledge of intermediate level solvers further our understanding of the development of strategy knowledge at the university level? The Pressley model of strategy knowledge proved effective in characterizing a broad range of strategy knowledge and should facilitate the

elaboration of strategy knowledge relevant to individual global strategies if appropriate tasks are defined.

In the analysis of the data, several trends appeared to be related to the sex of the solver. With regard to the proportion of time devoted to individual global strategies, one of the strongest patterns of difference across sex was that males tended to devote relatively more solving time to ANALYZE strategies. The mean proportion of solving time devoted to analysis on Task 1 was 22% for males and 13% for females. On Task 2, the proportions were 15% for males and 9% for females. Given the sample sizes, these results can only suggest that the trend observed may be worth following up. One of the few variations in beliefs across sex was that it was exclusively females who emphasized the importance of feelings and relating personally to a problem. If this trend is substantiated in further research, it could have important implications for the education of women students, particularly in biology, where objectivity appears to be valued by experts.

Based primarily on the general strategy knowledge reported, there are a number of potential research problems associated with the motivation patterns revealed in the results. What are the contributing factors to the strong performance-goal orientation observed among university level solvers? How are these beliefs manifested in the classroom? How can a learning-goal pattern of motivation be nurtured at the university level? These questions are especially important because of the secondary effects of these beliefs on specific strategy use and strategy acquisition.

A fourth area of research suggested by these results is the continued development of empirically-based models of process knowledge and the implementation of the specific results in the design of EC strategy instruction. Although the elaboration and analysis of EC strategy knowledge was by no means exhaustive, can these data begin to provide an effective framework for classroom instruction? Does the Pressley model, enhanced by empirically-based strategy knowledge, provide a framework that is useful to university-level educators in making process knowledge more explicit to our students? In each of these areas, there is a need for further research conducted from the perspective of enhancing the post-secondary learning experience.

### **In Conclusion**

In conclusion, it is clear from the results of this study that EC strategy knowledge played an important role in the problem solving of professors and students in both domains. This EC strategy knowledge consisted of general strategy knowledge, specific strategy knowledge and to a lesser extent, strategy acquisition knowledge. Across expertise, there were substantial gaps in all forms of EC strategy knowledge between professors and students and these gaps were not commonly addressed in university-level teaching. Across domains, there were fundamental differences in general strategy knowledge and more subtle differences in specific strategy knowledge. Since EC strategy knowledge is important to problem solving in each domain, has some domain specific elements and is commonly lacking in even intermediate level students, it appears to be an

important constituent of the body of knowledge which must be acquired to enable competent performance in a domain. The results presented here indicate that, in constructing the knowledge resource to support effective teaching of executive control strategy knowledge as an element of domain knowledge, the EC strategy knowledge of both students and professors can contribute to the development of empirically-based models of EC strategy knowledge. Furthermore, the development of such models should include a full range of general strategy knowledge, specific strategy knowledge and strategy acquisition knowledge, since all three forms of strategy knowledge interact in the effective acquisition and application of EC strategies.

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Appendix A: The Consent Form

CONSENT FORM

The University of Ottawa Human Research Ethics Committee requires that any research project involving human subjects must receive the informed consent of participants. This requirement has been put in place to assure the respect and confidentiality of the individuals involved. To fulfil this requirement, you are asked to carefully read the study description and conditions and, if willing, give your written consent to participate in this study.

Researcher: Lynn Taylor  
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 564-7722

The purpose of the study proposed by Lynn Taylor and supervised by J.P.Dionne of the University of Ottawa, is to investigate the problem solving strategies of university professors and students for the purpose of improving instruction at the university level.

The proposed study requires the participation of twenty professors and twenty students. In separate groups, students and professors will receive a brief presentation by the researcher and will be invited to participate in the study. Participation is wholly voluntary, with no direct benefit to the participants. All parties are free to decline, or to withdraw at any point in the procedure, without fear of repercussion. In the latter case, any data generated would be destroyed.

Those persons who volunteer to participate in the study will be asked to meet with the researcher in a private office setting for a single session, having a duration of one and one half to two hours. During this session, participants will receive training in the "think aloud while you solve a problem" technique, to the point where they are comfortable with thinking aloud as they work. Two experimental tasks will then be introduced, one at a time. These tasks consist of a description of two different problem scenarios, typical of real life situations found in the news media. Participants will be asked to study the scenario and work on resolving the problem. These problems do not involve mathematical calculations or 'trick questions'. Participants will be asked to report everything they are thinking as they work on the first problem. Pencil and paper will be provided. All verbalizations will be audio-taped for future analysis. Participants will then be asked to describe how they solved the problem. The reporting process will be

facilitated by questions from the researcher. The content of this report will also be audio-taped for future analysis. This procedure will be repeated for the second problem. Following these two rounds of problem solving, participants will be asked to rate the two problem scenarios with regard to four of the criteria which were used to design the problems. This task typically takes about five minutes. When these tasks have been completed, participants may, if they wish, receive immediate debriefing on how the data are to be utilized.

The confidentiality and anonymity of the participants will be safeguarded by the researcher. All tapes and transcripts will be identified only by code, and the key to the code will be held only by the researcher. The tapes and code key will be destroyed on completion of the study. In the presentation of the results of the study, participants will be identified only by their level of expertise (professor or student), the discipline area in which they work or study, and gender. Data is typically not used directly, but summarized for presentation. Direct quotes take the form of short (2-3 sentences) anonymous excerpts chosen to illustrate specific findings. When using such direct quotes, any references which would identify individuals or institutions would be deleted.

\*\*\*\*\*

**STATEMENT OF CONSENT**

I have read and understand the requirements of the study and consent to participate under the conditions described above. I have received a copy of the consent form.

Researcher: \_\_\_\_\_ Participant: \_\_\_\_\_  
Witness: \_\_\_\_\_ Date: \_\_\_\_\_

\*\*\*\*\*

Appendix A-1: Form For Additional Consent

**ADDITIONAL CONSENT**

(for inclusion of a full transcript in the results)

It is typical in the presentation of studies like this one to provide, as an appendix, one or two complete coded transcripts to demonstrate the data analysis procedure. The source of these transcripts will remain anonymous, identified only by level of expertise and chosen discipline . Any references identifying individuals or institutions will be deleted.

**STATEMENT OF CONSENT**

If the transcript of my problem solving is appropriate to illustrate the data analysis procedure, I give my consent to have it used under the conditions outlined above.

Researcher: \_\_\_\_\_

Participant: \_\_\_\_\_

Witness: \_\_\_\_\_

Date: \_\_\_\_\_

**APPENDIX B: CVP INSTRUCTIONS TO PROBLEM SOLVERS**

The goal of this research is to describe the knowledge that people use when they solve problems. The best way to find out about the knowledge that people use when they solve problems is to ask them to solve a problem while thinking aloud. When you think aloud, the objective is to verbalize as much as possible of what is going through your head. Almost anything you say will be good data for me. You won't be able to verbalize everything you think, but the idea is to give the best report of your thinking process that you can by talking constantly throughout the solving process.

Don't try to plan what you say. Your report does not have to be well structured or perfectly sequenced. What is most important is that you accurately reflect your thoughts, or even bits and pieces of your thoughts. Ideally, you should just try to echo directly out loud what is going through your mind, without paying too much attention to how it is coming out.

During the warm-up problems, we can discuss any questions you have about the procedure or the data you are generating. But during the experimental tasks, you will be on your own. I will try not to interact with you. The only time I will speak is if you stop verbalizing for more than a few seconds. Then I will remind you to keep talking.

Do you have any questions right now ?

Warm-up problems:

1. Solver's choice of:

**Counting boxes.** There are three separate, equal sized boxes, and inside each box there are two separate smaller boxes, and inside of each of the small boxes, there are four even smaller boxes. How many boxes are there all together? (Whimby and Lochhead, 1980).

or:

**Artificial language.** In a different language, luk eir lail means "heavy little package", bo lail means "heavy man" and luk jo means "pretty package". How would you say little man in this language?

2. Solver's choice of:

**Dog and Food matching.** There are four dogs sitting in front of their dog houses. The dogs in left to right order, are Pizza, Tiger, Lady and Sancho. Based on the information given below, figure out which dog eats Crunchy Blend dog food.

1. Pizza lives in a blue dog house.
2. The dog who lives in a red dog house eats Yummies.
3. Sancho eats Butcher Boy dog food.
4. Lady lives next to the dog with the green house.
5. Tiger lives next to the dog who eats Crunchy Blend.
6. The dog in the white house is next to the dog who eats Butcher Boy.
7. The dog who eats medium rare steak is farthest away from the dog who eats Butcher Boy.

or:

**Babysitting Cooperative.** In order to save money and their sanity, Melvin, Marc, Brock and Claire decide to form a babysitting cooperative. They agree to babysit for each other's children with the understanding that when one of them stays with another's children, the recipient will repay the sitter with an equal number of babysitting hours. They decide to tally babysitting hours at the end of the month. During the month, Melvin sat with Brock's children 9 hours, Marc sat with Melvin's children 3 hours and Claire stayed with Melvin's children 3 hours. Marc babysat 9 hours with Claire's children. Which of these people has 12 hours of babysitting due him or her? (Halpern, 1984).

If further training was required, the solver returned to the alternate problems in each pair.

**Appendix C: RD Interview Framework**

1. Have the solver generate a retrospective report, with as little interruption as possible.

**General Prompt:**

Can you describe in your own words, and in as much detail as possible how you solved the problem?

2. Questions arising from the CVP and RD reports. Where data allow, attempt to elaborate strategy knowledge in each major phase of problem solving.

**Sample prompts:**

**Reading:** When you were reading the problem, you underlined words in the text. Can you tell me more about that?

When you were reading the problem you elaborated on the text quite a bit to interpret parts of the problem text in your own words. Does that help you understand the problem?

**Analysis:** Were there specific cues in the text that made you want to examine the information more closely?

You mentioned your personal biases when you were solving the problem. Can you tell me more about how they influenced your solving?

**Planning:** You didn't talk about planning a lot, but you seemed to proceed in a systematic way. Can you tell me more about how you knew what to do to solve the problem?

**Verification:** If overt: What prompted you to go back and check over your solution?  
If not overt: How did you know you had a good solution?

3. More general questions addressed with each participant. These general prompts can develop into a sequence of related questions based on each participant's initial response.:

Do you like to solve problems?

Do you always solve problems in the same way or do circumstances affect how you solve problems?

What kinds of experiences have helped you learn to solve problems?

**APPENDIX D:**

**PROBLEM RATINGS**

Each of the two problems you have solved were developed based on a set of design criteria. As a person who has solved each of these problems, you are probably the best judge of the degree to which each problem meets certain design criteria. Based on your own experience with solving the two problems, please choose from the five point scale provided the response which most accurately describes your agreement with each statement in the table below.

(1) strong agree (2) agree (3) feel ambiguity (4) disagree (5) strongly disagree

Statement	Problem B (moose)	Problem P (single mothers)
1. This problem does not have a single, correct response. It may have a number of correct responses.		
2. The solution of this problem requires the solver to use further information from memory and/or external sources in the solving process.		
3. There is more than one possible series of problem solving steps which could result in a solution to this problem.		
4. This problem requires the problem solver to make decisions about the relative importance and specific roles of the problem components.		

Strategy	Definition and Prototype Example(s)	Code
READ (Global)	<ul style="list-style-type: none"> <li>● includes first reading of the problem statement, attempts to absorb the contents of the statement and re-reading of any part of the problem statement during the solving process.</li> </ul>	R:
Specific Strategies		
First reading	<ul style="list-style-type: none"> <li>● first reading of the problem statement.</li> </ul> Prototype example: "OK. Experimental Task B. In a remote, 100,000 square kilometre area of northern British Columbia a chain of low mountains...(to end of text)." (PSP-7, 4-43).	R:1
re-reading	<ul style="list-style-type: none"> <li>● re-read any part of the problem statement for the information given, or the task required. This may occur at any point in the solving process.</li> </ul> Prototype example: (explicit) "...so.. I am going to go through it again. OK. A maritime city of about 200,000..." (BS-6, 47-49). (in context) "...you allot some of them to doing child care...history of outpatient psychiatric care, limited education...um..OK." (PSS-4, 95-98).	R:re
monitor important information	<ul style="list-style-type: none"> <li>● identify important or interesting information in the problem text during the reading stages. Important elements can be underlined, written down or mentally flagged.</li> </ul> Prototype examples: "...a ban on wolf hunting which is now entering its tenth year...Underline tenth year...(BS-4, 29-31). "OK. Neither of these things have very much to do with it...The fact that this is a maritime city might though...(BS-6, 50-52).	R:imp
elaborate meaning	<ul style="list-style-type: none"> <li>● elaborate the meaning or significance of phrases from personal knowledge during reading. Elaboration may be verbal or involve imagery.</li> </ul> Prototype examples: "so the extended family would mean...grandparents...etcetera...(BS-4, 468-470). "A maritime city...OK. Now I harken back to my short visits to the maritimes...I have a picture of the maritimes in my head as I do that...Nova Scotia and New Brunswick...(PSS-2, 304-309).	R:elab

Strategy	Definition and Prototype Example(s)	Code
monitor difficulty of the problem	<ul style="list-style-type: none"> <li>● monitor the degree of difficulty of the problem from a personal perspective while reading.</li> </ul> Prototype example: "OK. This is a hard one..." (PSP-8, 592-593).	R:diff
monitor familiarity of problem	<ul style="list-style-type: none"> <li>● identify the problem as familiar or unfamiliar, or more specifically, by domain, process or analogy.</li> </ul> Prototype examples: "Ah...well it struck me as just a classic example of population biology..." (BP-2, 121-123). "I don't know anything about moose, wolves and hunting." (PSP-8, 572-574).	R:fam
evaluate understanding of the problem statement	<ul style="list-style-type: none"> <li>● any effort to determine if the problem statement is clear to the solver.</li> </ul> Prototype examples: (local) "Now is that the cattle farming, the big game hunting, or both?" (PSP-7, 66-68). (global) "...I have to read slowly and I still don't know what this thing is about." (PSP-8, 13-15).	R:und
generate a representation of the problem	<ul style="list-style-type: none"> <li>● any effort to summarize or diagram the problem statement, in the process of synthesizing a representation of the problem.</li> </ul> Prototype example: "what I did was sort of sketch out who the groups are and what their interest are." (PSP-7, 170-172).	R:rep
monitor interest	<ul style="list-style-type: none"> <li>● monitor whether the problem is interesting to the solver.</li> </ul> Prototype example: "I am sort of interested in questions of the ecology." (PSP-1, 940-941).	R:int
ANALYZE (global)	<ul style="list-style-type: none"> <li>● if a solution path is not apparent following the reading of a problem, the problem solver can undertake an analysis of the conditions and goals of the problem and the perspectives that might be taken. Although analysis departs from merely reading and understanding the text, it is well structured and directly addresses information given in the problem statement.</li> </ul>	A:

Strategy	Definition and Prototype Example(s)	Code
critically analyze information given	<ul style="list-style-type: none"> <li>critically consider the source, quality, implications or gaps in information given in the problem statement.</li> </ul> Prototype example: "Is it really the case that is used here that the wolves are decimating the moose?...Is that actually valid?...I suppose that it would be important in some way to establish...If there were data over a number of time points to be able to establish if a correlation is actually true." (BP-5, 144-152).	A:info
identify sub-problems	<ul style="list-style-type: none"> <li>identify sub-problems within the original problem statement.</li> </ul> Prototype example: "No, we have two problems here...One is finding out and knowing how many you can shoot, and two is enforcing that." (PSS-4, 973-976).	A:sub
identify links between problem elements	<ul style="list-style-type: none"> <li>consider how the elements of the problem are linked and interact.</li> </ul> Prototype example: "So probably the fact that they are intermittent residents of half-way houses..just goes back to the fact that they have low wages, which goes back to the fact again that they have limited education." (BS-6, 147-153).	A:link
monitor perspectives	<ul style="list-style-type: none"> <li>identify one or more perspectives from which the problem is, or can be viewed. This strategy can include recognizing the constraints a perspective places on how the problem can be solved.</li> </ul> Prototype examples: "I would say you have two choices...You can worry about the animals or you can worry about the economics." (BS-2, 186-188).	A:per
monitor personal biases	<ul style="list-style-type: none"> <li>recognize personal beliefs, emotions or biases with regard to the problem situation.</li> </ul> Prototype example: "OK...So this would be easier for someone who is more into hunting, but anyway...(PSS-4, 920-923).	A:bias

Strategy	Definition and Prototype Example(s)	Code
monitor assumptions	<ul style="list-style-type: none"> <li>● identify the assumptions within the problem statement or in how the problem is interpreted.</li> </ul> Prototype example: "OK. Assuming...based on statistics, that these women are fairly young..." (BS-4, 523-525).	A:assm
historical analysis	<ul style="list-style-type: none"> <li>● undertake an historical analysis to find possible causes or solutions.</li> </ul> Prototype example: "Again I would have to use some concept of history in the sense that...obviously before single mothers did not occur...This wasn't a major problem. Or the few that were there were handled by the extended family.(..) With the out-migration, many of these women are left without extended family." (BP-2, 370-389).	A:his
restructure the problem	<ul style="list-style-type: none"> <li>● restructure the problem using a different interpretation of given information or information other than that from the problem text.</li> </ul> Prototype example: "...Um...actually no, the problem is not moose and wolves at all. The problem is the economy. Oh shoot! I misunderstood this. OK. So the problem is the faltering economy." (PSP-8, 605-611),	A:rest
identify a starting point	<ul style="list-style-type: none"> <li>● identify a point from which to begin solving the problem.</li> </ul> Prototype example: "I guess what is going through my mind is where do you start? This is a circle...;a sort of spiralling circle. Where do you intervene to change anything?" (PSP-1, 67-71).	A:start
EXPLORE (global)	<ul style="list-style-type: none"> <li>● If analysis does not yield a solution pathway, the problem solver may broaden the problem space to search for relevant information and procedures. Exploration is distinguished from analysis in that it is characterized as a search for information which lies outside the problem statement. It is more loosely structured and may range some distance from the problem statement.</li> </ul>	E:

Strategy	Definition and Prototype Example(s)	Code
explore likely sources of information	<ul style="list-style-type: none"> <li>● identify possible sources of needed information. Prototype example: "We need some assistance in solving this problem. I think we have to enlist the aid of ..(..)...perhaps government social services (...)educators, I would want to meet with social workers and I would want to meet with other experts...and talk about these various options.." (BP-3, 1163-1176).</li> </ul>	E:
explore available information	<ul style="list-style-type: none"> <li>● explore existing knowledge stores for information useful in solving the problem. Prototype example: "...What I've read, I've found that's usually not the answer. Wolves in general...in general struggle to find food. ah...I don't think they would decimate moose on their own. (BS-2, 154-160).</li> </ul>	E:info
select relevant information	<ul style="list-style-type: none"> <li>● select information from the explored areas for inclusion in the problem solving process. Prototype example: "So we have government support in the area of child care, ahm...securing loans for both child care and...maintaining their households with regards to going to school...you have some who are...doing the child care...the government employs counsellors or pays for counsellors. Because in the end they just end up paying more welfare..." (PSS-4, 148-158).</li> </ul>	E:sel
explore analogies	<ul style="list-style-type: none"> <li>● explore analogous situations from existing knowledge. Prototype example: "...to make sure that it is not...that there aren't other factors involved...like health factors...like with the elk recently...(.) It seemed to be correlated with the wolves, but it was something in the elk population itself." (BP-5, 174-184).</li> </ul>	E:
PLAN (global)	<ul style="list-style-type: none"> <li>● The problem solver outlines one or more tentative pathways to a solution of the problem or any part of the problem, before producing a solution.</li> </ul>	P:

Strategy	Definition and Prototype Example(s)	Code
outline a plan	<ul style="list-style-type: none"> <li>● outline or diagram a framework for attacking the problem, or any part of the problem.</li> </ul> Prototype example: "OK...so we need education and daycare...and then afterwards...we are going to need some sort of job placement program..." (BP-6, 185-189).	P:out
consider alternative plans	<ul style="list-style-type: none"> <li>● consider possible alternative ways to solve the problem.</li> </ul> Prototype example: "So that again, if there wasn't money to set up new programs, one could in fact, integrate this issue into an existing program." (BP-5, 127-130).	P:alt
evaluate the plan	<ul style="list-style-type: none"> <li>● evaluate the likely effectiveness of the plan, either directly, or by considering the implications of the plan.</li> </ul> Prototype example: (Direct) "...Long term economic plan would no doubt be helpful. But it is unlikely in an immediate direct sense to have much of an impact of the problem at hand." (PSP-7, 542-546). (implication) "...and maybe that could help the outfitters and maybe that could let the population grow...however, that might be slightly difficult since...100,000 square kilometres...it's mountainous valleys...(abandons idea of a census determined kill). (BS-4, 105-111),	P:eval
modify the plan	<ul style="list-style-type: none"> <li>● modify the plan if the solving process reveals new information or an element of the problem not previously considered.</li> </ul> Prototype example: "OK...So that then adds another issue as far as...when we talk about support groups...in the medical sense as in the...in the sense of family support group there needs to be more expert care for this group of women...OK." (BP-5, 873-880).	P:mod

Strategy	Definition and Prototype Example(s)	Code
monitor difficulty	<ul style="list-style-type: none"> <li>● monitor difficulty encountered during the planning of a solution. This may include wavering confidence or difficulty in staying on track.</li> </ul> Prototype examples: "So I am becoming sidetracked is what I am becoming." (BP-3, 988-989). "I really do not feel too confident about solving this problem by myself." (BP-3, 1157-1159).	P:diff
IMPLEMENT (global)	<ul style="list-style-type: none"> <li>● The problem solver states a solution, moving from considering what could be done to what will be done.</li> </ul>	I:
solution statement	<ul style="list-style-type: none"> <li>● bring together the solving process in a solution statement.</li> </ul> Prototype example: "At this point I would stop and say that what I need to do is consult after I have laid out the problem. That I then need to go and consult with somebody who would address the self-esteem thing...at the same time as I would be getting training for work, child care and...social programs that would allow for that transition." (PSP-8, 118-129).	I:soln
provide reasons	<ul style="list-style-type: none"> <li>● provide reasons or evidence for decisions and points made in the solution process.</li> </ul> Prototype example: "...The population of the wolves could be monitored in some way. So it could be controlled to a certain level so that there wouldn't be these wild fluctuations...in populations which had been seen in the past where the farmers practically eliminated them...To prevent the swings...back and forth." (BP-5, 235-244).	I:rea
VERIFY (global)	<ul style="list-style-type: none"> <li>● The problem solver verifies the outcome of the solution process in the context of the plan or the problem posed. This verification is at a global level, considering the final outcome of the process as opposed to the local assessments made during the solving process.</li> </ul>	V:

Strategy	Definition and Prototype Example(s)	Code
evaluate the solution	<ul style="list-style-type: none"> <li>● critically review the solution to the problem in terms of the problem statement or plan.</li> </ul> Prototype example: "So maybe this is not a good solution at all...So basically, I can't solve this problem. (PSP-8, 666-669).	V:eval
evaluate the limits of the solution	<ul style="list-style-type: none"> <li>● recognize the limitations of the solution offered.</li> </ul> Prototype example: "...in terms of counselling...so this is going to be a pretty big bill and they won't want to do it." (PSS-4, 175-177).	V:lim
consider alternative outcomes	<ul style="list-style-type: none"> <li>● consider whether there are other possible solutions or explanations that the one arrived at.</li> </ul> Prototype example: "Alternatively...I don't know how feasible it would be...but you could also move the wolves...relocate them somewhere else...(PSS-5, 92-95).	V:alt

Definitions and Guiding Questions Facilitating the Coding of Global Strategies.

Definition	Guiding Questions
<b>READ:</b> Includes the first reading of the problem statement, any attempts to absorb the contents of the statement, and the rereading of any part of the problem statement during the solving process.	<ol style="list-style-type: none"><li>1. Does the episode involve direct reading of at least part of the problem text?</li><li>2. Except for rereading episodes, does the episode occur early in the problem solving episode?</li><li>3. Does the episode involves direct interaction with the problem test in the effort to absorb important words, conditions or goals, as they are stated?</li><li>4. Does the episode involve some assessment by the problem solver or how well the problem text is understood before beginning to solve the problem?</li></ol>

CODE = R:

**ANALYZE:**

If a solution path is not apparent following the reading of a problem, a problem solver can undertake an analysis of the conditions or goals of the problem and the perspectives that might be taken. Although analysis departs from merely reading and understanding the text, it is well structured and directly addresses information given in the problem statement.

CODE = A:

**EXPLORE:**

If analysis does not yield a solution pathway, the problem solver may broaden the problem space to search for relevant information or procedures. Exploration is distinguished from analysis in that it is characterized as a search for information which lies outside the problem statement. It is more loosely structured and may range some distance from the problem statement.

CODE = E:

1. Does the episode involve critical consideration of the conditions, information or goals stated in the problem text as opposed to understanding the text as given?
  2. Does the episode involve an awareness of possible assumptions, perspectives or the influence of personal biases in the problem scenario?
  3. Does the episode involve breaking the problem into a number of more manageable problems?
  4. Does the episode involve reformulating the problem from a different perspective or knowledge base?
- 
1. Does the episode involve calling to mind prior knowledge or experience that may be useful in solving the problem?
  2. Does the episode involve consideration of knowledge which lies outside of the information given in the problem text?
  3. Does the episode involve the selection of relevant information which can be imported to the problem solving process?

**PLAN:**

The problem solver outlines one or more tentative pathways to a solution of the problem, or any part of the problem, before producing a solution.

**CODE = P:**

1. Does the episode involve one or more global or specific plans for approaching the problem or any part of the problem?
2. Does the episode occur in advance of a solution to the problem?
3. Does the episode function to direct or organize subsequent action in the problem solving process.
4. Is the episode tentative in nature, consisting of what might be done as opposed to stating what should be done?

---

**IMPLEMENT:**

The problem solver formulates a solution to the problem.

**CODE = I:**

1. Does the episode involve a statement of solution?
2. Can the episode be characterized as a statement of what would be done, as opposed to more tentative planning statements?
3. Does the episode provide reasons or evidence for the solution as stated?

**VERIFY:**

The problem solver verifies the outcome of the solution process in the context of the solution plan or the problem posed. This verification is at a global level, assessing the final outcome of the solving process, as opposed to local assessments made during the solving process.

CODE = V:

1. Does this episode constitute a review of the solution?
  2. Does the episode involve an assessment of the overall solution process or outcome in terms of the problem statement or plan?
  3. Does the episode involve an assessment of confidence in the outcome?
  4. Does the episode involve consideration of the limitations of the proposed solutions?
-

**APPENDIX G: A Full Inventory of Reported Conditional Knowledge**

**Table G-1 Conditional Knowledge Relevant to READ Strategies**

**Table G-2 Conditional Knowledge Relevant to ANALYZE Strategies**

**Table G-3 Conditional Knowledge Relevant to EXPLORE Strategies**

**Table G-4 Conditional Knowledge Relevant to PLAN Strategies**

**Table G-5 Conditional Knowledge Relevant to IMPLEMENT Strategies**

**Table G-6 Conditional Knowledge Relevant to VERIFY Strategies**

**Table G-7 Conditional Knowledge Reports of Each Global Strategy by Group**

Frequency of Reports of Conditional Knowledge  
Relevant to READ Strategies

Specific Conditional Knowledge Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
<b>RE:1 First Reading</b>				
C1 - gives a general overview of the problem	3	3	1	1
C2 - read slowly to retain information	1	1	0	2
C3 - identify important information during first reading	2	4	1	1
C4 - identify important information following first reading	3	3	0	2
* C5 - skim through the problem on first reading	1	1	0	0
C6 - the problem can be anticipated during first reading	2	2	2	1
Group Totals	12	14	4	7
<b>R:re Re-reading</b>				
C7 - more than one reading of the problem text is necessary	2	1	0	3
C8 - the amount of re-reading is influenced by familiarity	1	2	1	0
C9 - re-read text if uncomfortable with comprehension	2	2	0	1
C10 - re-read to identify and remember important information	4	3	1	5
C11 - re-read late in solving to verify solution	1	2	0	1
* C12 - re-read more critically than in first read	1	0	0	0
* C13 - re-read less if time is limited	0	1	0	0
Group Total	11	11	2	10
<b>R:imp Monitor Important Information</b>				
C14 - it is important to identify all relevant information	2	3	1	0
C15 - circle or underline important information	3	6	0	4
C16 - write down important information	1	4	1	2
C17 - numbers and chronological information are important	1	4	0	0

TABLE G-1

Specific Conditional Knowledge Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
C18 - actors and their interest are important information	0	0	0	3
C19 - the time/effort required to identify important information is influenced by familiarity	2	4	0	1
C20 - highlighting important information facilitates understanding	0	2	0	2
C21 - focus on highlighted information when returning to text	0	4	0	3
<b>Group Total</b>	<b>9</b>	<b>27</b>	<b>2</b>	<b>15</b>
<b>R:int Monitor Interest</b>				
C22 - interest in a problem positively influences effort expended	0	4	5	6
C23 - real life relevance positively influences effort expended	0	1	3	3
C24 - strong personal identification with problem enhances problem solving	0	3	4	4
C25 - solve problems for extrinsic rewards	1	4	0	2
*C26 - if uninteresting, artificially create interest	0	0	1	0
<b>Group Interest</b>	<b>1</b>	<b>12</b>	<b>13</b>	<b>15</b>
<b>R:elab Elaborate Meaning</b>				
C27 - connects problem information with solver's knowledge	0	2	2	2
*C28 - elaborate more if problem is unclear	0	1	0	2
*C29 - elaborate more in familiar context	0	1	1	0
C30 - elaboration helps to focus on and remember information	0	1	1	2
C31 - verbal elaboration is useful	5	9	3	6
C32 - visual elaboration (imagery) is useful	1	0	4	4
*C33 - do not use elaboration in math problems	0	1	0	1
<b>Group Total</b>	<b>6</b>	<b>15</b>	<b>11</b>	<b>17</b>
<b>R:und Monitor Understanding</b>				
*C34 - be sure to understand the problem before solving	1	2	0	0

TABLE G-1

Specific Conditional Knowledge Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
C35 - consciously monitor understanding	0	1	1	2
C36 - problem should be coherent and make sense	0	1	1	2
*C37 - do not persist in trying to understand	0	1	0	0
*C38 - whether you understand the problem may not be evident until you being to solving	2	0	0	0
Group Totals	3	5	2	4
<b>R:diff Monitor Difficulty During Reading</b>				
C39 - more difficult if the kind of problem is unfamiliar	3	1	1	0
C40 - more difficult if you lack training or knowledge in the problem domain	1	3	1	2
C41 - people problems are more difficult	3	2	0	1
C42 - number problems are more difficult	2	0	1	2
*C43 - abstract or hypothetical problems are more difficult	0	1	0	0
*C44 - problems with complex text are more difficult	0	0	0	1
C45 - perceived difficulty influences how a problem is approached	3	1	1	1
C46 - suspicious if a problem seems too simple	2	1	0	1
*C47 - asks 'can this problem be solved?' before beginning	0	0	1	0
Group Totals	16	9	5	8
<b>R:fam Monitor Familiarity</b>				
C48 - familiarity is based on solving similar problems	1	3	2	2
C49 - familiarity provides a solving framework	1	3	0	1
C50 - familiarity is based on substantive knowledge in the problem domain	2	1	1	0
C51 - familiar problems are easier to solve	1	3	5	4
C52 - more information is available in familiar problems, but they may not be easier	2	0	1	1

TABLE G-1

Specific Conditional Knowledge Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
C53 - processing will be more conscious in an unfamiliar context	0	3	2	1
C54 - less comfortable in an unfamiliar context	2	0	2	1
*C56 - one is not to be fooled by apparent familiarity	0	2	0	1
Group Totals	9	15	13	11
<b>R:rep Generate a Problem Representation</b>				
C57 - it is essential to develop a problem representation	2	1	3	3
C58 - reducing the problem text makes the problem more manageable	3	4	0	5
C59 - represent the problem in a diagram	3	2	2	2
C60 - a diagram is more effective in revealing relationships between problem elements	1	0	3	3
C61 - express the problem in your own words	1	2	0	2
C62 - use underlined/circled words as representation	0	3	0	2
C63 - identify and write down the crux of the problem	3	3	1	4
C64 - identify the big picture in which the problem sits	2	2	0	1
C65 - use your own representation of the problem when solving	3	1	1	2
*C66 - visualize the problem scenarios	0	1	0	1
Group Total	18	19	10	25
Total items of Conditional Knowledge for READ Strategies	85	127	62	112

**Note:** An Asterisk (\*) denotes items not included in the tables of conditional knowledge presented in Chapter 4.

Frequency of Reports of Conditional Knowledge  
Relevant to ANALYZE Strategies

Specific Conditional Knowledge Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
<b>A:info - Critically Analyze Information Provided</b>				
C67 - consider whether problem information is correct/valid	4	1	2	4
C68 - determine if the information given is complete	6	2	5	0
C69 - carefully dissect given information	2	3	1	5
C70 - exercise a systematic skepticism	2	0	4	3
C71 - weight the importance of factors/variable	1	3	1	2
*C72 - analyze more if prior knowledge is available	0	2	0	1
*C72 - analyze more if prior knowledge is scant	0	1	1	0
*C73 - analyze more if there is no obvious solution path	1	0	0	0
*C74 - analyze carefully to avoid being misled	2	1	0	0
*C75 - make a conscious effort to analyze	1	0	0	0
<b>Group Totals</b>	<b>19</b>	<b>13</b>	<b>14</b>	<b>15</b>
<b>A:bias - Monitor Personal Biases</b>				
C76 - personal views shape how a problem is seen and solved	0	0	8	5
C77 - recognize personal views, but keep them aside	6	2	3	2
C78 - it is acceptable to use own views in problem solving	0	4	0	3
*C79 - do not like to reveal own views	0	0	2	1
C80 - own views enhance problem solving	0	3	0	2
C81 - do not let own views dominate	2	1	2	3
C82 - personal involvement in a problem increases difficulty	2	3	2	3
<b>Group Totals</b>	<b>10</b>	<b>13</b>	<b>17</b>	<b>19</b>

TABLE G-2

Specific Conditional Knowledge Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
<b>A:per - Monitor Perspective</b>				
C83 - establish a perspective from which the problem is, or can be, viewed	2	0	3	0
C84 - take a broad, 'big picture' perspective	0	0	6	3
C85 - take an objective perspective	6	2	3	2
C86 - the perspective taken to influenced by knowledge and beliefs	0	0	4	3
C87 - consider multiple perspectives	0	0	2	4
C88 - it requires effort to shift perspectives	0	0	3	1
C89 - flexible in shifting perspectives	0	0	0	3
*C90 - assume active roie as the problem solver	1	0	0	1
Group Totals	9	2	21	20
<b>A:rest - Restructure the Problem</b>				
C91 - restructure a problem when it does not make sense	1	0	6	4
C92 - restate the problem is more general, abstract terms	1	3	5	0
*C93 - restructure less if problem is unfamiliar	1	0	2	0
*C94 - evoked by a particular cue in the problem	0	1	1	0
Group Totals	3	4	14	4
<b>A:link - Identify Links Between Problem Elements</b>				
C95 - finding linkages requires conscious effort	1	3	0	3
C96 - elements of a problem should fit together	1	0	3	1
C97 - understanding how problem elements interact is important	4	0	2	3
C98 - writing down or diagramming problem helps reveal links	1	1	2	3
*C99 - prior knowledge influences linkages	0	0	1	0
*C100 - more linked elements in real life problems	0	1	0	0
Group Totals	7	5	8	10

TABLE G-2

Specific Conditional Knowledge Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
<b>A:his - Historical Analysis</b>				
C101 - historical analyses can reveal the cause of the problem	2	1	1	3
C102 - historical analysis can provide solution ideas	2	1	1	3
*C103 - is a biology strategy	2	0	0	0
*C104 - chronology is important	1	1	0	0
*C105 - historical analysis creates a problem context	1	0	0	0
<b>Group Total</b>	<b>8</b>	<b>3</b>	<b>2</b>	<b>6</b>
<b>A:assm - Monitor Assumptions</b>				
C106 - critically examine underlying assumptions	2	0	2	0
*C107 - critically examine your own assumptions	1	0	0	0
<b>Group Total</b>	<b>3</b>	<b>0</b>	<b>2</b>	<b>0</b>
<b>A:sub - Identify Sub-problems</b>				
*C108 - it is useful to divide the problem in manageable parts	2	1	0	0
*C109 - make a conscious effort to identify sub-problems	1	0	0	2
*C110 - finding sub-problems is easier in familiar contexts	0	1	0	0
<b>Group Total</b>	<b>3</b>	<b>2</b>	<b>0</b>	<b>2</b>

TABLE G-2

Specific Conditional Knowledge Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
<b>A:start - Identify a Starting Point</b>				
*C111 - somewhere in the problem is a clue to get started	1	0	0	0
*C112 - thinking about similar problems is useful	0	1	0	0
Group Totals	1	1	0	0
<b>Total items for Conditional Knowledge for ANALYZE Strategies</b>	63	43	78	76

**Note:** An Asterisk (\*) denotes items not included in the tables of conditional knowledge presented in Chapter 4.

Frequency of Reports of Conditional Knowledge  
Relevant to EXPLORE Strategies

Specific Conditional Knowledge Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
<b>E:sour Explore Possible Sources of Information</b>				
C113 - consult with experts to find information	3	0	3	1
*C114 - consult books to find information	0	1	2	0
*C115 - confidence in our area make it possible to consult other experts	0	0	1	0
Group Total	3	1	6	1
<b>E:info Explore Available Information</b>				
C116 - intentionally search for existing knowledge that would help understand/solve the problem	0	5	3	4
*C117 - explores information without conscious effort	1	0	0	0
C118 - both academic and personal knowledge are useful	2	4	2	1
*C119 - exploration can provides missing information	0	0	0	2
*C120 - recognize limits/extent of existing knowledge	0	0	2	0
Group Totals	3	9	7	7
<b>E:agy Explore Useful Analogies</b>				
C121 - actively search for relevant analogies	0	4	1	4
*C122 - analogies just 'pop' into your head	0	0	0	1
C125 - analogies are more difficult to find in unfamiliar contexts	1	1	0	2
*C124 - analogies can provide a starting point	0	1	0	0
*C125 - analogies can provide a source of information	0	0	0	1
C126 - analogies can provide a solution framework	0	2	1	3

TABLE G-3

Specific Conditional Knowledge Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
*C127 - analogies will be difficult to use if they do not map well to the present scenario	0	1	0	2
Group Totals	1	9	2	13
<b>E:sel Select Relevant Information</b>				
*C128 - is more difficult in unfamiliar contexts	2	1	0	0
*C129 - need to focus and reduce available information	0	1	2	0
*C130 - brainstorm first, then select information	0	1	0	2
*C131 - more difficult to select if you have a lot of knowledge	0	0	1	1
Group Totals	2	3	3	3
Total items of Conditional Knowledge for EXPLORE strategies	9	22	19	24

**Note:** An Asterisk (\*) denotes items not included in the tables of conditional knowledge presented in Chapter 4.

Frequency of Reports of Conditional Knowledge  
Relevant to PLAN Strategies

Specific Conditional Knowledge Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
<b>P:out OUTLINE A PLAN</b>				
*C132 - it is essential to plan	1	0	1	1
C133 - solve with information at hand, rather than extensive planning	0	0	0	3
C134 - identify a global goal to guide planning	2	1	2	6
C135 - write down elements of the plan	1	2	0	5
C136 - be ordered and systematic in planning	1	2	1	2
*C137 - use a general framework only	0	0	0	1
*C138 - an experimental framework is useful	2	0	1	0
C139 - if familiar, the problem can be solved directly from experience and prior knowledge	3	0	0	1
*C140 - remain open to new ideas during planning	0	1	0	2
<b>Group Totals</b>	<b>10</b>	<b>6</b>	<b>5</b>	<b>21</b>
<b>P:eval EVALUATE THE PLAN</b>				
C141 - to avoid getting on the wrong track	2	2	0	3
C142 - refer back to the problem when planning	3	1	1	1
C143 - explore the consequences of planning ideas	0	1	1	3
*C144 - compensates for disorganization/distraction	1	0	1	1
*C145 - evaluate plan more carefully than solution	0	0	0	1
<b>Group Totals</b>	<b>6</b>	<b>4</b>	<b>3</b>	<b>9</b>

TABLE G-4

Specific Conditional Knowledge Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
<b>P:diff MONITOR DIFFICULTY DURING PLANNING</b>				
*C146 - difficulty can surface during the solving process	1	0	0	0
*C147 - work on paper if difficulty is encountered	0	0	0	1
*C148 - planning is easier if there are clear choices/paths	1	1	0	1
*C149 - monitor not only difficulty, but progress	1	0	0	0
*C150 - difficult problems require more planning	1	1	0	1
Group Totals	4	2	0	3
<b>P:alt CONSIDER ALTERNATIVE PLANS</b>				
C151 - it is important not to get caught in the first idea that comes to mind	1	0	0	3
C152 - required conscious effort	2	0	1	2
*C153 - requires time	1	0	0	0
*C154 - more frequently if not comfortable in a domain	1	0	0	0
*C155 - less frequently if stressed	0	1	0	0
Group Totals	5	1	1	5
Total items of Conditional Knowledge for PLAN Strategies	25	13	9	38

Note: An Asterisk (\*) denotes items not included in the tables of conditional knowledge presented in Chapter 4.

Frequency of Reports of Conditional Knowledge  
Relevant to IMPLEMENT Strategies

Specific Conditional Knowledge Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
<b>I:soln MAKE A SOLUTION STATEMENT</b>				
C156 - you should consider alternative solutions	2	2	2	3
<b>I:rea</b>				
*C157 - provide as many reasons as you can to support your solution	0	2	0	1
*C158 - if you can't rationalize your solution, it is probably flawed	1	1	0	0
Group Totals	1	3	0	1
Total items of Conditional Knowledge for IMPLEMENT Strategies	3	5	2	4

Frequency of Reports of Conditional Knowledge  
Relevant to VERIFY Strategies

Specific Conditional Knowledge Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
<b>V:eval EVALUATE THE SOLUTION</b>				
C159 - it is important to check all solutions	2	2	0	2
C160 - more likely to evaluate if solution is complex	3	0	0	0
*C161 - more likely to evaluate ill structured problems	0	0	0	1
C162 - more likely to evaluate if there is a specific right answer	2	2	2	2
C163 - evaluation varies with the familiarity of the problem	2	0	2	2
*C164 - more likely to evaluate if problem is important	0	1	0	1
*C165 - more likely to evaluate if others appear to have difficulty	1	0	1	0
*C166 - more likely to evaluate if aware that problem was not treated thoroughly	1	0	0	0
C167 - evaluate by considering consequences	0	0	2	2
C168 - evaluate by checking solution against problem statement	1	4	1	3
C169 - evaluate reasoning as well as substance of solution	1	1	0	5
C170 - remain open to modify solution	1	2	2	0
C171 - it is difficult to change solution	1	2	0	2
C172 - require knowledge to judge solution	2	1	1	0
C173 - evaluate solution to avoid embarrassment	1	1	2	1
*C174 - should feel personally comfortable with a solution	0	0	0	2
*C175 - solutions based on personal knowledge are weaker	0	0	2	0
C176 - solutions should be practical, make sense	1	1	1	2
*C177 - use cycles of evaluation to refine solution	0	0	0	1

TABLE G-6

Specific Conditional Knowledge Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
*C178 - evaluate solution for degree of compromise	0	0	0	1
*C179 - skip evaluation if time is short	0	0	0	2
*C180 - frequently do not verify	0	0	0	1
Group Totals	19	17	16	30
<b>V:alt CONSIDER ALTERNATIVE SOLUTION</b>				
C181 - it is important to seek alternative solutions	2	2	2	3
*C182 - requires time	0	1	0	0
*C183 - not required to get marks	0	1	0	0
*C184 - increases likelihood of reaching a compromise	0	0	0	2
Group Totals	2	4	2	5
Total items of Conditional Knowledge for Verify Strategies	21	21	18	35

**Note:** An Asterisk (\*) denotes items not included in the tables of conditional knowledge presented in Chapter 4.

TABLE G-7

The Frequency of Conditional Knowledge Reports of  
Each Global Strategy By Group

Global Strategy	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
READ	85	127	62	112
ANALYZE	63	43	78	76
EXPLORE	9	22	18	24
PLAN	25	13	9	38
IMPLEMENT	3	5	2	4
VERIFY	21	21	18	35
TOTALS	206	231	187	289

**APPENDIX H: A Full Inventory of Reported General Strategy Knowledge**

**Table H-1            Beliefs Relevant to the Problem Solving Process and Self as Problem Solver**

**Table H-2            Beliefs Relevant to Confidence**

**Table H-3            Beliefs Relevant to Time and Objectivity**

**Table H-4            Beliefs Relevant to Solving Problems With Others**

Frequency of Reports of Beliefs Relevant to the  
Problem Solving Process and Self as Problem Solver

Specific Beliefs Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
<u>Characterization of Process</u>				
- solve problems following a general framework	3	3	3	6
- solving varies between solvers and tasks	2	1	0	1
- problem solving is a linear process	3	0	0	1
- problem solving can be unconscious	3	1	0	0
- problem solving can be brought under conscious control	2	0	1	1
*- problem solving requires information	0	2	0	2
*- problem solving requires imagination	2	0	0	0
- real life problem solving is different than academic problem solving	1	2	3	2
*-real life problem solving is less rigorous	0	0	1	1
*- real life problem solving is more difficult	1	1	1	0
- a real life context adds constraints	0	0	1	3
Group Totals	17	9	10	17
<u>Self as Problem Solver</u>				
- enthusiastic about problem solving	5	3	2	5
- does not like solving problems	0	1	1	2
- gets a kick out of finding a solution	4	1	1	2
- solves problems primarily for extrinsic rewards	1	4	0	1
- prefers well-structured problems	3	2	0	1
- likes ill-structured problems	0	0	1	3
- likes logic problems/puzzles	5	0	0	2
- dislikes logic problems/puzzles	0	0	4	0
- does not like math problems	2	0	1	2
- be organized and careful in thinking	3	3	0	1
*- does not like to be organized in thinking	0	1	1	1
- a desire to do well	2	0	2	2
*- believes high effort is important	0	0	1	0

TABLE H-1

Specific Beliefs Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
*- novel solutions are superior	2	0	1	0
Group Totals	27	15	15	23

**Note:** An Asterisk (\*) denotes items not included in the tables of conditional knowledge presented in Chapter 4.

Frequency of Reports of Beliefs Relevant to  
Confidence

Specific Beliefs Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
<b>GENERAL</b>				
- generally not confident	0	2	2	3
*- generally confident	1	1	0	0
*- confidence is important in problem solving	0	0	0	2
* - does not like to feel tested	0	1	2	0
<b>RISK TAKING</b>				
*- likes a challenge	0	1	0	2
- avoids challenge	2	1	3	1
<b>FAILURE</b>				
- wants to have the correct answer	3	2	4	2
- fears failing	3	0	0	1
- feels bad if solution is inadequate	2	1	1	0
*- anxiety about failing reduces ability to solve	0	2	1	0
<b>LESS CONFIDENCE</b>				
- if the problem context is unfamiliar	5	2	3	0
*- influenced by the confidence of others	1	2	0	0
<b>MORE CONFIDENCE</b>				
- if you have academic knowledge in the area	0	4	5	0
- if you have hard data to work with	2	0	2	0
- if you have experience with similar problems	2	3	2	2

**Note:** An Asterisk (\*) denotes items not included in the tables of conditional knowledge presented in Chapter 4.

Frequency of Reports of Beliefs Relevant to  
TIME and OBJECTIVITY

Specific Beliefs Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
<b>TIME</b>				
- insufficient time is a problem	1	3	0	2
- time constraints cause stress which reduces problem solving ability	2	5	1	2
- accepts time constraints	1	0	0	4
- need time to produce optimum solution	1	1	1	3
- difficult problems require more time	2	1	0	1
- it is important to get the right answer, fast	0	3	2	0
Group Totals	7	13	4	12
<b>OBJECTIVITY</b>				
- personal experiences and feelings motivate and provide input for problem solving	0	3	0	3
- be aware of personal feelings, but do not let them dominate	2	1	2	3
- uncomfortable with revealing personal views in problem solving	4	0	1	2
*- an experimental framework enhances objectivity	2	0	0	0
*- work with bare facts to transform the subjective to objective	2	0	1	0
*- can not be value free	0	0	1	1
Group Totals	16	6	8	10
Frequency of positive statement about objectivity	14	2	5	3
Frequency of negative statements about objectivity	2	4	3	7

**Note:** An Asterisk (\*) denotes items not included in the tables of conditional knowledge presented in Chapter 4.

Frequency of Reports of Beliefs Relevant to  
SOLVING PROBLEMS WITH OTHERS

Specific Beliefs Reported	Group			
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)
<b>GENERAL</b>				
- problem solving is primarily a solitary activity	6	4	1	3
- does not like to solve a problems in front of others	3	2	1	0
- prefers to solve problems with others	0	1	4	1
- willing to solve alone, then explain solution to others	3	0	0	1
*- group problem solving requires an effective leader	0	0	2	1
*- does not like to solve with strangers	1	1	1	0
*- a combination of solitary and group solving is most effective	0	0	2	1
<b>EFFECTS</b>				
- just verbalizing your thoughts, even if you receive no input fro others, is useful	1	0	3	0
- solving with others broadens and enriches thinking	1	2	5	4
*- group solving is faster	0	0	1	1
*- feels more confident about a group solution	0	0	1	1
<b>CONSULTATION</b>				
- consults experts when solving a problems outside of area of expertise	3	0	3	1
- does not readily consult in own area	2	1	1	0
*- consults in own area	0	0	2	1
*- consults more as he/she gets older	1	0	1	0
	21	11	28	15
Frequency of positive statements about solving with others	6	4	24	10
Frequency of negative statements about solving with others	15	7	4	5

Note: An Asterisk (\*) denotes items not included in the tables of conditional knowledge presented in Chapter 4.

1 Appendix I: A Coded Protocol

2 BS-6. Male. March 15,1991.

3 R: You can begin whenever you are  
4 ready.

5 P: OK.. In a maritime city of about  
6 200,000 ..... in the past/  
7 enjoyed a stable work force which  
8 has allowed successive generations  
9 of a family to earn a livelihood./  
10 . In this stable environment, family  
11 responsibilities such as child  
12 rearing/ had been shared among  
13 extended family. OK/.. Ahm.. The  
14 industrial job base has been  
15 steadily eroded over the last  
16 decade/ and the sagging economy has  
17 altered ... is altering the  
18 character/ of the city... Members  
19 of many of many families who have  
20 been long time residents/ of the  
21 city have been forced to find  
22 employment elsewhere, disrupting/  
23 extended family networks. One of  
24 the problems to emerge following  
25 this outmigration/ is that about a  
26 particular group of about 60 single  
27 mothers..../ Just underlining that  
28 little bit.../ have found  
29 themselves on the margins of  
30 society. The women in this marginal  
31 group have had a history of out-  
32 patient/psychiatric care, and have  
33 been intermittent residents of half  
34 way houses./ These women have  
35 received limited education, and if  
36 they are employed, accept menial/  
37 work, and low wages.... These  
38 circumstances give rise to low  
39 self/ esteem, and consequently,  
40 these women assume the role of  
41 victim in assessing their  
42 situations/ and feel powerless to  
43 act on their own to change their  
44 social situations.../ As a person  
45 assigned to resolving this case,/   
46 how would you propose to help these  
47 women to become reintegrated into  
48 society?/ Oh.... The first thing  
49 that strikes me is that I really  
50 don't know much about this issue,/   
51 so.. I am going to have to go

R:1

R:imp

1 min.

R:1

R: fam

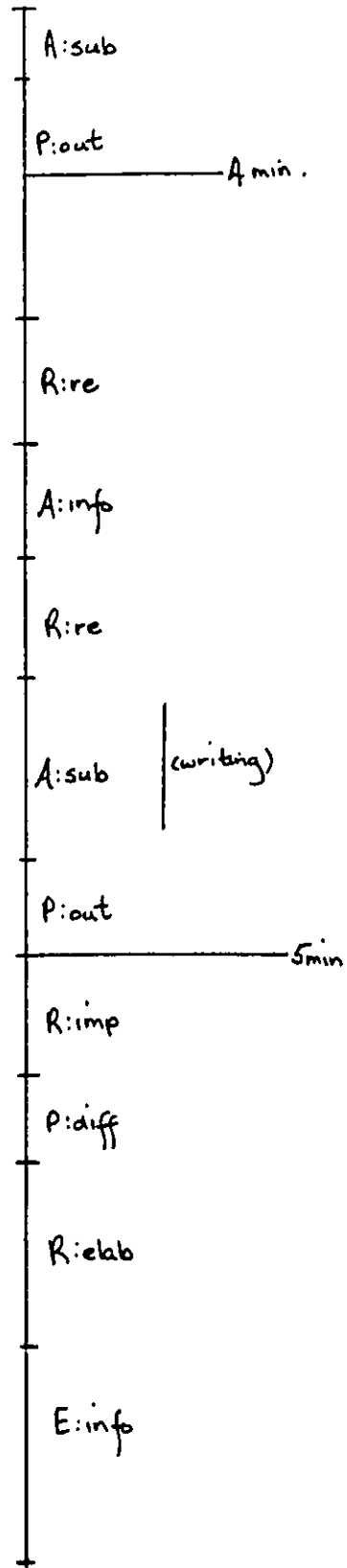
R:re

R:re  
cond.

Appendices...300

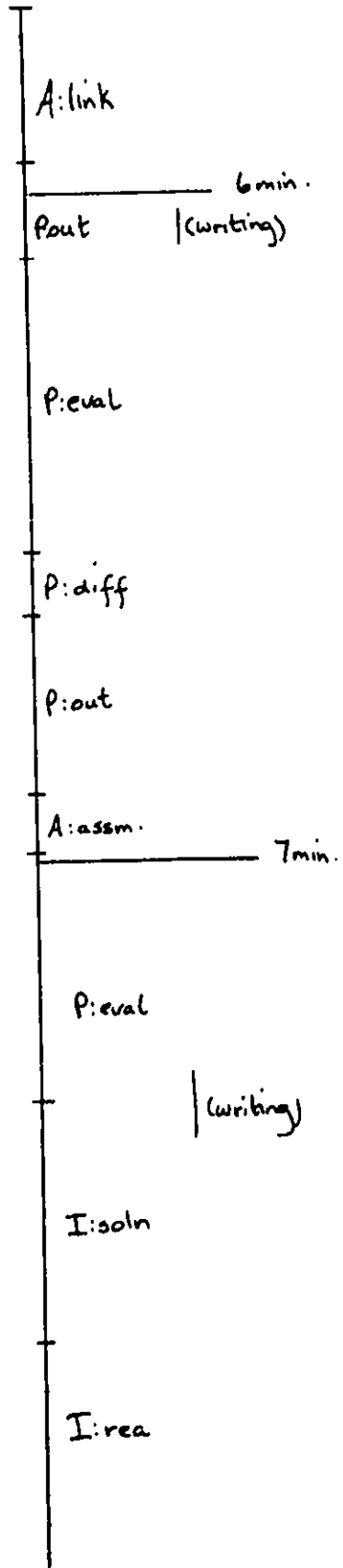
<p>52 through it again... OK./ A Maritime          53 city of about 200,000 ..... OK.          54 Neither of/ those things have very          55 much to do with it .... The fact          56 that is maritime might though.../          57 In the past has enjoyed a stable          58 workforce which has allowed          59 successive generations of a family/          60 to earn a livelihood. .... Shared          61 by extended family/..... OK. ...          62 So/ I am realizing now that the          63 child rearing that was done before          64 by the extended family/... now has          65 to be done by these women because          66 they are all by themselves./ So          67 that is something that really          68 doesn't fit into their society.....          69 The industrial/ job base has been          70 steadily eroded over the last          71 decade, and the sagging economy/ is          72 altering the character of the city.          73 ... OK... So these single mothers/          74 really aren't the only people who          75 are being affected. It sounds like          76 the city is falling into shambles./          77 So.. Members of many families who          78 have been long time residents/ of          79 the city have been forced to find          80 employment elsewhere, disrupting          81 extended family networks./          82 OK..So... The industrial job base          83 is eroding/ so.... that means          84 probably a lot of jobs that would          85 be appropriate for/these women are          86 eroding too, because if they aren't          87 educated,/ they could easily do          88 some sort of industrial job..... so          89 it looks like/ first of all they          90 are lacking people to keep care of          91 their kids,/.... and also they are          92 lacking opportunity for          93 employment/.... The women in this          94 marginal group have a history of          95 outpatient/ psychiatric care, and          96 have been intermittent          97 residents/... ah.. residents of          98 half way houses... These women have          99 received limited education,../ Ok..          100 That's going to be important... and          101 if they are employed accept menial          102 work/ and low wages.... These          103 circumstances give rise to low self</p>	<p>R:re</p> <p>R:imp</p> <p>R:re ————— 2 min</p> <p>R:elab</p> <p>A:info</p> <p>R:re</p> <p>R:elab</p> <p>R:re</p> <p>R:elab ————— 3 min</p> <p>R:rep   (writing)</p> <p>R:re</p> <p>R:imp   (writing)</p>
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104 esteem./ Ok. So... another problem  
 105 for these women is their low self  
 106 esteem.../ If you wanted to fix  
 107 their low self esteem/ according to  
 108 what's given here we should try to  
 109 find/ them work with higher wages  
 110 that isn't menial and in order/ to  
 111 find.... in order to find something  
 112 like that , really, they have to  
 113 have more education/..... OK.  
 114 Consequently, these women assume  
 115 the role/ of victim in assessing  
 116 their situations/ and feel  
 117 powerless to act on their own to  
 118 change their social situations./  
 119 OK.. It seems to me that it would  
 120 be natural that they should feel  
 121 powerless since they/ have low self  
 122 esteem.... So, as a person assigned  
 123 to resolving this case how would  
 124 you propose/ to help these women  
 125 become reintegrated into  
 126 society?... OK.../ It seems.. OK.  
 127 One of the major problems here is/  
 128 .. ahm.. that somehow, in order for  
 129 them to do anything/ that is going  
 130 to raise their self esteem, they  
 131 need someone to take care of their  
 132 children,/ so I am just marking  
 133 that down as a major point ... that  
 134 maybe some sort of daycare would  
 135 help these women out/.. Now... So  
 136 there are 60 of them, so that is a  
 137 fair number/.... Ahm.. They've  
 138 been... they have a history of  
 139 outpatient psychiatric/ care....  
 140 OK. I really don't quite know how  
 141 that's going to fit into/ this  
 142 yet... They have been intermittent  
 143 residents of half way houses/...so  
 144 I guess that must mean that they  
 145 have some type/ of criminal record,  
 146 but it mustn't be that severe,  
 147 since this is only half way  
 148 houses/... And .. well that seems  
 149 logical to me that if they have low  
 150 self esteem,/ and if they have to  
 151 work for really low wages, if money  
 152 is a real problem for them that  
 153 they/ probably would have to commit  
 154 theft or something to be able to  
 155 raise/ their family.... So probably



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156 the fact that they are intermittent  
 157 residents of half way/ houses ...  
 158 Just goes back to the fact that  
 159 they have low wages,/ which goes  
 160 back to the fact again that they  
 161 have limited education... So I  
 162 think if/ these women became  
 163 educated .. that it would solve a  
 164 lot of things/..... If they became  
 165 educated, they wouldn't have to  
 166 accept menial work or low wages/ ..  
 167 and that way.. OK. .. So that way  
 168 it would raise their/ self esteem,  
 169 and they would also be receiving  
 170 enough money that/ ... not while  
 171 they are being educated, but some  
 172 time consequently,/.. that they  
 173 wouldn't have to steal in order to  
 174 make money./ OK... So I still don't  
 175 know how this outpatient  
 176 psychiatric care fits in. Now.../  
 177 These women assume the role of  
 178 victim ... If some sort of daycare/  
 179 system ...were established, such  
 180 that/ these women could finish  
 181 their education,..../ because they  
 182 have limited education ..I would  
 183 probably assume that they hadn't  
 184 even finished highschool.../ So  
 185 probably if there were some kind of  
 186 daycare system/ that would permit  
 187 them to go to school and finish  
 188 their highschool education at  
 189 least, that way/ they could get  
 190 jobs with at least a little better  
 191 work, or.. You know, maybe they  
 192 could do a college program/ too...  
 193 In any case, education definitely  
 194 seems/ to be a ... key thing  
 195 here..... and.../ OK.. so we need  
 196 education and daycare, and then  
 197 afterwards.../ we are going to need  
 198 some sort of child placement  
 199 program/ because ahm.. they could  
 200 only.. If these women couldn't find  
 201 a job,/ they would probably would  
 202 become even more frustrated and  
 203 their self esteem would become even  
 204 lower and they would have/ to  
 205 commit more theft and everything  
 206 else... and I am sure that would  
 207 contribute to their psychiatric

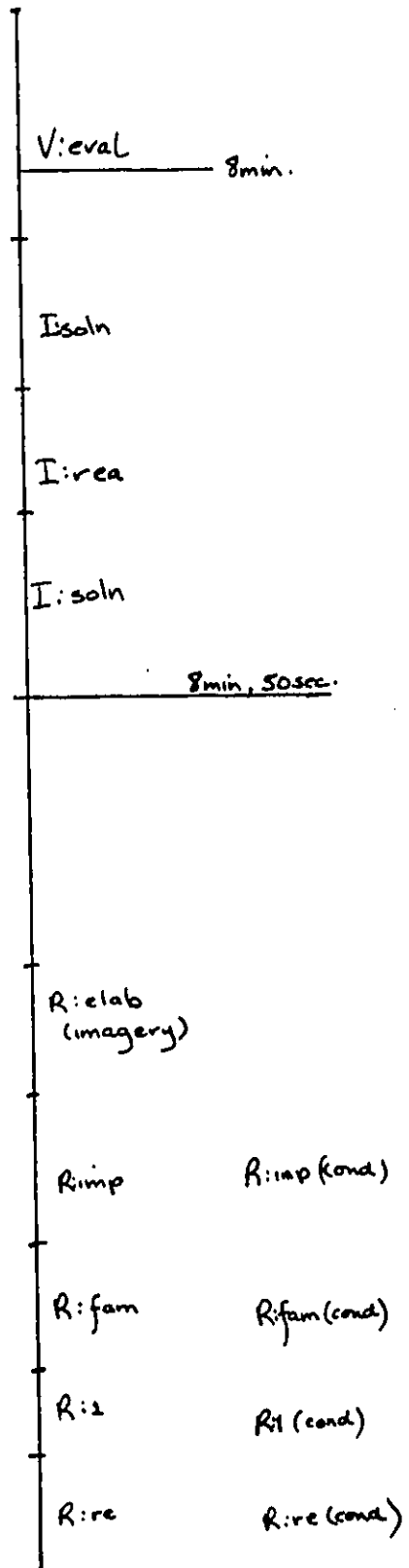


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208 state/... So , in getting more  
 209 education, .. I am sure that they  
 210 would feel better/ enough about  
 211 themselves and they would feel more  
 212 capable of raising their families/  
 213 and everything else. So probably  
 214 their psychiatric nature/ .. their  
 215 psyche would improve, .. so.. I  
 216 think/ the three things, Daycare,  
 217 education, and job placement/ ...  
 218 are what I would .. I would do to  
 219 integrate these women into  
 220 society/... because they could  
 221 become integrated once their self  
 222 esteem was improved/... once they  
 223 had money to raise their children  
 224 properly .. ah.. the daycare would  
 225 have to be something that would  
 226 have to go on/ ...into while they  
 227 are working... ah.../ so the three  
 228 things then are daycare, education  
 229 and job placement/ that I would  
 230 do..... OK?../....

231 R: That's good data. That's great.  
 232 Now, while it is really fresh to  
 233 you, I would like you to go back to  
 234 when you first started reading the  
 235 problem and describe to me in as  
 236 much detail as you can, how you  
 237 solved it, just in your own  
 238 words...

239 P: OK. Ahm.. First of all.... Well,  
 240 just reading it, I conjured up  
 241 images into my mind so I could  
 242 think of what the city must look  
 243 like and stuff like that... And  
 244 the fact that it was a maritime  
 245 city really didn't have any  
 246 importance for me so I just blocked  
 247 it out... Ahm.. I went through and  
 248 I just .. At first it really seemed  
 249 foreign to me... I really couldn't  
 250 relate to the problem because I  
 251 haven't taken any psychology  
 252 courses or anything... so the first  
 253 time I read it through it was  
 254 really just to get the information  
 255 into my mind... Then when I went  
 256 through again, I just wanted to  
 257 find the problems because this  
 258 proposes to help the women become  
 259 reintegrated into society... So



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260 basically you had to underline the  
 261 problems that were facing these  
 262 women . So I went through and found  
 263 .... the things that seemed to be  
 264 the most problematic for me like...  
 265 limited education really stuck  
 266 out... and the fact that they had  
 267 to work for low wages... That stuck  
 268 out as well. And not everything at  
 269 first clicked. I didn't know was it  
 270 important that there were 60 single  
 271 mothers? I didn't know whether that  
 272 was important... That they were  
 273 single I knew was important because  
 274 .. ah.. ... Being single mothers,  
 275 no one is going to be able to look  
 276 after their kids.... and .. while  
 277 they are doing anything, so ahm..  
 278 The fact that they were single  
 279 mothers was really important and it  
 280 became obvious to me right away  
 281 that it was going to become  
 282 necessary to have some sort of ....  
 283 some sort of daycare to take care  
 284 of their children. and... I .. The  
 285 fact that they were in out-patient  
 286 psychiatric care, I really... I  
 287 couldn't really figure that out for  
 288 a while... And then the fact that  
 289 they were intermittent residents of  
 290 half way houses.. I didn't think  
 291 that would be important.. I didn't  
 292 really make the relation right  
 293 away... Once I started putting the  
 294 relation together about limited  
 295 education and low wages being  
 296 related to their low self esteem  
 297 and the fact that they feel  
 298 powerless ... That's when it  
 299 started to see a relation between  
 300 low self esteem, feeling powerless  
 301 and the fact that they were  
 302 outpatient psychiatric care....  
 303 they are single mothers, they are  
 304 their only income... so probably  
 305 the reason they are in psychiatric  
 306 care is because they can't handle  
 307 not being able to raise their  
 308 family the way they would like  
 309 to... Ah.. So, then I felt I knew I  
 310 had everything I needed to solve  
 311 the problem... I just had to work

R:imp

R:imp (cond)

R:elab

R:diff

R:imp

A:link

A:info

A:info (cond)

312 it out. So ... knowing that if they  
 313 had daycare, education would be  
 314 possible and I started thinking  
 315 about the program at my old high  
 316 school for mothers to come back and  
 317 finish their high school ... so..  
 318 then I thought that education would  
 319 be useful.. Then job placement.. I  
 320 just thought about how a lot of  
 321 people get educated but then they  
 322 can't get any work and that would  
 323 probably be even more detrimental  
 324 for these poor women. ....  
 325 R: I had a number of questions that  
 326 I wanted to ask you ...  
 327 P: OK.  
 328 R: When you were describing how you  
 329 solved that problem, you said some  
 330 things that piqued my interest. One  
 331 of them was that you said you got a  
 332 mental picture of the situation. Do  
 333 you usually try to do that .. To  
 334 visualize the problem?  
 335 P: I think I normally do... Yes.  
 336 Even if it is just something.. say  
 337 a biology problem .. say just  
 338 describing some sort of habitat  
 339 where there is this many  
 340 individuals,.. even if my diagram  
 341 isn't that useful .. I might do  
 342 something like this.... You know ..  
 343 just a square with writing the  
 344 number of animals that are in it or  
 345 something .. Or ... I normally  
 346 visualize..  
 347 R: The other thing that I was  
 348 noticing when you were solving it  
 349 was that you systematically gave  
 350 reasons for the things you were  
 351 deciding. Are reasons important? If  
 352 you saw a solution where there were  
 353 reasons would that be a better  
 354 solution to you?  
 355 P: Definitely....  
 356 R: Can you tell me more?...  
 357 P: Let me see ... I.. well  
 358 basically I guess when I am solving  
 359 a problem, I figure that if I can't  
 360 rationalize every step, then ... I  
 361 may be going wrong some where and  
 362 .. with a problem, if you make a  
 363 mistake at the beginning, you could

P:out

E:agy (not in CVF)

V:Lim

R:elab

R:elab (cond)

I:rea

I:rea

I:rea (cond)

364 wind up really far off at the end.  
 365 So I try and rationalize everything  
 366 as I am going along... and that's  
 367 why, when I reach something that  
 368 doesn't make any sense to me , it  
 369 throws in a wrench into the  
 370 gears.... because I don't know if  
 371 this is going to throw me off  
 372 somewhere back in the beginning...  
 373 R: But you did check back for that  
 374 this time.... You went through once  
 375 and you noticed a few things... You  
 376 went through again and you noticed  
 377 more things, but you kept checking  
 378 them against each other.. Were you  
 379 conscious of doing that?  
 380 P: Um-hum... I guess .. Well going  
 381 through and noting all the points..

Irea

Irea (cond)

382 Maybe the fact that they were in  
 383 outpatient psychiatric care ...  
 384 Maybe that had absolutely nothing  
 385 to do with it... Just like in the  
 386 beginning they said a maritime city  
 387 with potted plants on every street  
 388 corner or something.... It is  
 389 something that maybe wasn't  
 390 important so, .... I always like  
 391 checking the data against each  
 392 other because something like this  
 393 ahm... It just doesn't just work in  
 394 a .... like a step by step  
 395 thing..... Everything is  
 396 interrelated.. so checking things  
 397 against everything else.... This is  
 398 like a real word problem, so ...  
 399 everything does have to check  
 400 against everything else.... R: You  
 401 have told me quite a lot and I want  
 402 to avoid covering the same ground  
 403 again.. Let's see... I would like  
 404 to ask you about the fact that this  
 405 problem wasn't familiar to you. Did  
 406 that influence your approach?  
 407 P: Ahm.. I think basically it made  
 408 me feel a little more uneasy  
 409 because ... ahm.. in my program now  
 410 I have taken enough biology courses  
 411 that ... when I am faced with a  
 412 biology problem ... even if I am  
 413 not extremely well prepared that  
 414 particular problem,... I can

R:imp

R:imp (cond)

A:link

A:link (cond)

R:fam

General  
 Strategy  
 Knowledge  
 R:fam (cond)

415 normally put stuff out from ...  
 416 from previous experience. And this  
 417 was a completely foreign situation  
 418 for me. .. My brother would be able  
 419 to do it really well because it is  
 420 what he is doing at school. But for  
 421 me, it wasn't something I could  
 422 really relate to and I think that  
 423 if it were something that I had ...  
 424 you know, school experience to fall  
 425 back on , I would feel more  
 426 comfortable.. R: Do you think it  
 427 made you more careful or systematic  
 428 .. in any respect?  
 429 P: Ahm... I think it made me go  
 430 about it... yeah , I would say more  
 431 systematically, maybe... ahm.. it  
 432 made me slow down, because..... I  
 433 had to... work with the facts that  
 434 were in the problem because I  
 435 didn't have any of my own facts to  
 436 go that much on ... Like in a  
 437 biology problem, ... I can just.. I  
 438 can flip more rapidly between  
 439 things because I am more used to  
 440 doing it and I already know that  
 441 ... Like I would know naturally  
 442 that two facts should normally fall  
 443 together or that things should go  
 444 in this particular order.... I  
 445 didn't know what order things  
 446 should fall in, in this problem.  
 447 R: But you knew that you didn't  
 448 know...  
 449 P: (laughter) Yeah.....  
 450 R: Do you want to take a deep  
 451 breath before the next problem? ...  
 452 Whenever you are ready, you can  
 453 begin by reading it out loud and  
 454 then continuing to verbalize... You  
 455 are doing a good job.  
 456 P:: OK. The first thing I noticed  
 457 is ... ahm.. it's a 100,000 square  
 458 kilometre area.../ and in the last  
 459 problem, the second phrase was an  
 460 number too, so I think that is kind  
 461 of interesting..../ OK. In a  
 462 remote, 100,000 square kilometre  
 463 area of northern British Columbia,/   
 464 a chain of low mountains forming  
 465 numerous valleys has traditionally  
 466 been rich/ in wildlife, including

General  
 Strategy  
 Knowledge  
 R: fam(cond)

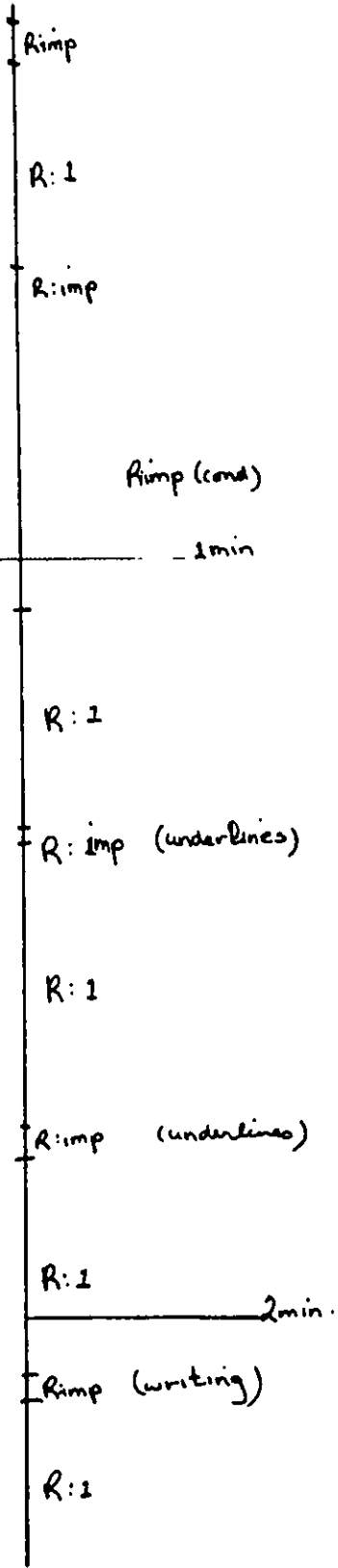
Rifam Rifam(Cond)

A:inf A:info (cond)

R:int

R: 1

467 large populations of moose ..  
 468 underline../ and wolves..  
 469 underline.. Ahm.. Historically,  
 470 this flourishing wildlife/  
 471 supported the hunting and trapping  
 472 practices of the area's  
 473 native people. .. More recently/  
 474 these resources supported the  
 475 establishment of small towns/  
 476 ..OK.. And this was more recently,  
 477 so I am underlining that... And  
 478 traditionally../ I think that is  
 479 important too. Ahm... I guess the  
 480 reason/ I am underling both of them  
 481 is that I notice that they are both  
 482 giving a time reference/ and they  
 483 both have different data following  
 484 them so.. there must be something  
 485 important relating to time/ in the  
 486 problem even though I don't know  
 487 yet... Ah... With economies/ based  
 488 primarily on cattle farming and out  
 489 fitting for big game hunting./ The  
 490 establishment of these towns has  
 491 affected the populations of moose  
 492 and wolves/ in particular. About 20  
 493 years ago, wolves were hunted/  
 494 almost to extinction by farmers....  
 495 OK. resulting on a ban on wolf  
 496 hunting/ which is now entering its  
 497 tenth year.../... Big game  
 498 outfitters are currently  
 499 complaining to provincial  
 500 authorities/ that since it became  
 501 illegal to intentionally kill  
 502 wolves, the wolf/ population  
 503 appears to have increased, and the  
 504 moose population decreased,/ ...  
 505 OK. That seems important../ to the  
 506 extent where the hunters are going  
 507 elsewhere to hunt../ OK..  
 508 elsewhere to hunt.  
 509 They argue that the wolves are  
 510 decimating the moose/ and they  
 511 claim that the most effective way  
 512 to revive the faltering economy/  
 513 ... faltering economy .... is to  
 514 revoke the ban on killing wolves./  
 515 If you were the person assigned to  
 516 resolving this case, how would you  
 517 go about deciding on a solution/ to  
 518 the declining moose population

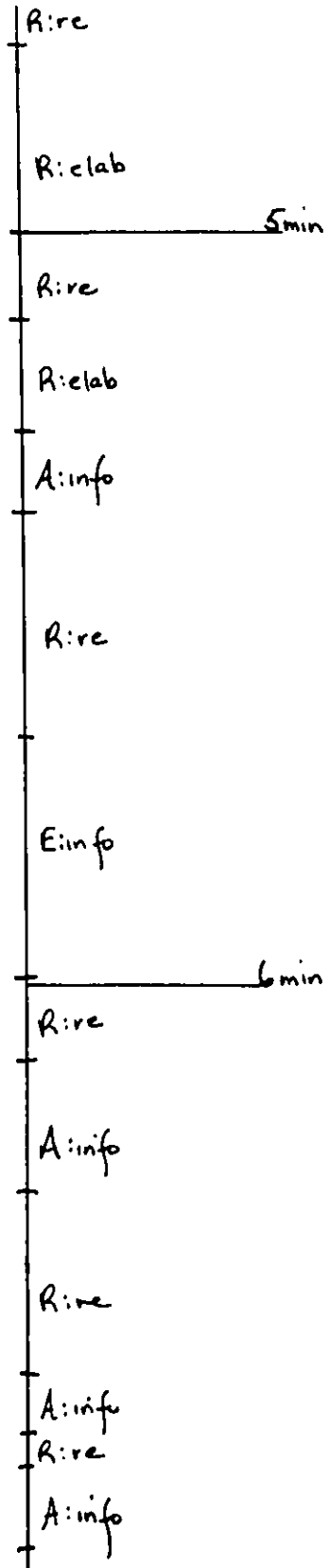


519 problem?  
 520 OK./..... OK. I got a lot/ of facts  
 521 out of it that time ... but I am  
 522 going to go through it again,  
 523 So.../ The fact that this area is  
 524 remote might be important.../ Ahm..  
 525 The area of it .. I don't really  
 526 think is going to be that  
 527 important.../ but it might be. And  
 528 the fact that it is in British  
 529 Columbia really doesn't really mean  
 530 anything.../ A chain of low  
 531 mountains forming numerous  
 532 valleys.../ Ahm.. I really don't  
 533 think low mountains and numerous  
 534 valleys have much to do with it/  
 535 ... have been rich in wildlife.../  
 536 including large populations of  
 537 moose and wolves... OK./ So before  
 538 there were tons of moose and tons  
 539 of wolves... both of them.../ OK.  
 540 So it is interesting that before,  
 541 there were large populations of/  
 542 both... so I am just going to write  
 543 that down/..... So/ before, when  
 544 there were no constraints placed on  
 545 either population/ by man, both  
 546 populations were large.../ So  
 547 historically, this flourishing  
 548 wildlife supported the hunting and  
 549 trapping practices/ of the area's  
 550 native people..... OK. Ahm../ Those  
 551 things interest me.. the hunting  
 552 and trapping practices of the  
 553 area's native people/.. ahm.. Even  
 554 though .. I said before there were  
 555 no constraints/ placed on them by  
 556 man, but there were because native  
 557 people were hunting and trapping./  
 558 So ... native.. hunting and  
 559 trapping.../... Ahm.. I am just  
 560 remembering that a lot of people  
 561 say that native/ people... live in  
 562 harmony/ with their wilderness and  
 563 that their methods of hunting and  
 564 trapping work/ in ... work ....  
 565 with nature./ Whereas it seems like  
 566 white men just can't do anything  
 567 right/ when it come to hunting and  
 568 trapping . It is kind of the sad  
 569 truth of the deal I guess./  
 570 Most recently, these resources

R:imp  
 R:re  
 R:imp.  
 3 min.  
 R:elab  
 R:imp R:imp (cond)  
 R:elab  
 R:re  
 R:int  
 R:re  
 A:info  
 4 min.  
 R:imp (writing)  
 E:info  
 R:re

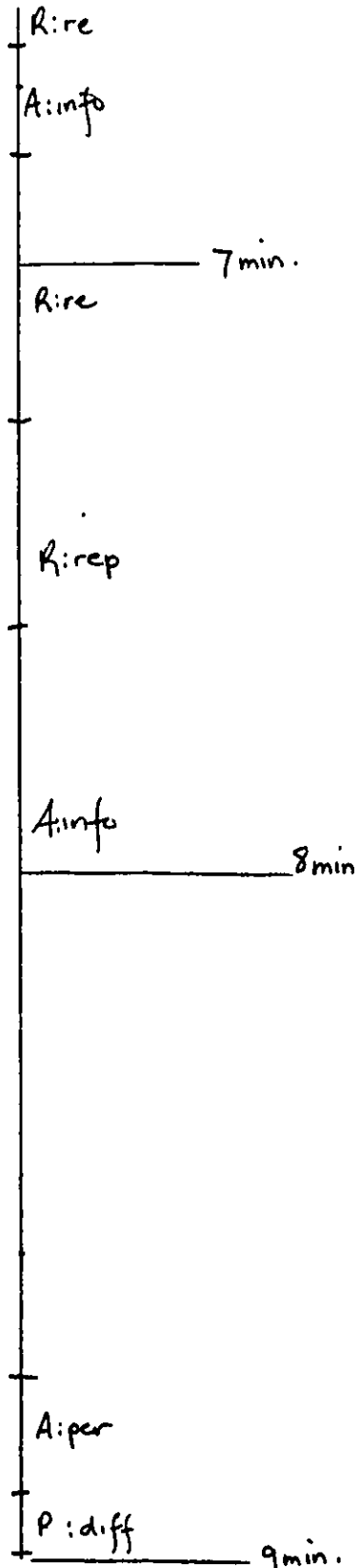
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571 supported the establishment of  
 572 small towns ... So/ that means that  
 573 the establishment of small towns  
 574 were based on the hunting and  
 575 trapping practices,/ so they had  
 576 economies partly based/ on cattle  
 577 farming and outfitting for big game  
 578 hunting/... OK. These small towns  
 579 .. based on cattle farming and big  
 580 game hunting.../ Hunting and  
 581 trapping. OK. So these towns  
 582 established themselves/ on the  
 583 moose and wolf populations  
 584 basically/ because on cattle  
 585 farming... By introducing cattle  
 586 farming, they must have cleared a  
 587 lot/ of land in order to do it.  
 588 OK../. The establishment of these  
 589 towns has affected the populations  
 590 of moose and wolves in particular..  
 591 Twenty years ago,/ wolves were  
 592 hunted almost to extinction by  
 593 farmers, resulting in a ban in wolf  
 594 hunting which is now entering its  
 595 tenth year/. OK. The fact that the  
 596 wolves were almost/ driven to  
 597 extinction.. tells me that any  
 598 population that they could have  
 599 now, since it is only 20 years ago/  
 600 is probably going to be... really  
 601 going to be really variable/ in  
 602 numbers because they were reduced  
 603 to such a small number before/...  
 604 so.. resulting in a ban on wolf  
 605 hunting which is now entering its  
 606 tenth year./ So.. I would say that  
 607 probably the .../ population has  
 608 increased significantly since the  
 609 ban was put in place,/ but that the  
 610 population is still really variable  
 611 .../ So big game outfitters are  
 612 currently complaining to provincial  
 613 authorities that since it became  
 614 illegal/ to intentionally kill  
 615 wolves, the wolf population appears  
 616 to have increased./.. OK. Well  
 617 that's normal that it should have  
 618 increased./ .. and the moose  
 619 population decreased../ It is also  
 620 normal that the moose population  
 621 should have decreased since there  
 622 are more wolves around./ .. To the

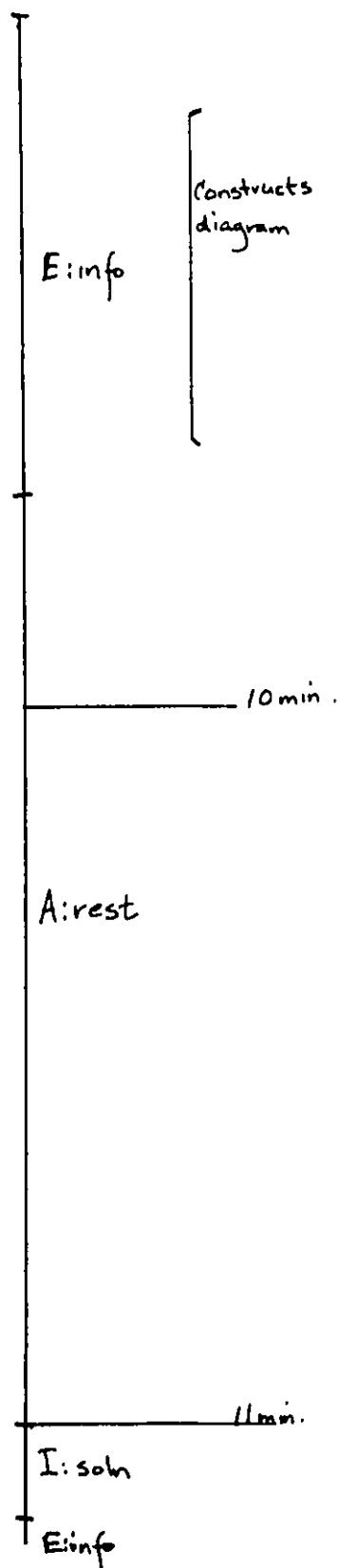


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623 extent where hunters are going  
 624 elsewhere to hunt./ Well, I guess  
 625 if they are not going to have as  
 626 good as chance to catch the moose  
 627 they are going to go elsewhere/  
 628 so... They argue the wolves are  
 629 decimating the moose and they claim  
 630 that the most effective way to  
 631 revive the economy/ is to revoke  
 632 the ban on killing wolves.../ I  
 633 guess.. as assigned to resolving  
 634 this case, how would I go about  
 635 deciding/ on a solution to the  
 636 declining moose population problem?  
 637 OK../..../. The moose population  
 638 is going down.. Ah./..... Ok. The  
 639 moose population is going down  
 640 because the wolf population/ has  
 641 gone up. The wolf population went  
 642 up ./.. because of... a ban was  
 643 put/ on killing wolves. Ahm.. It  
 644 would seem to me that the people ..  
 645 /that are running the big game  
 646 resorts right now../ aren't really  
 647 conscious of .. Like they don't  
 648 really .. They aren't interpreting  
 649 properly/ what they are seeing.  
 650 Ahm... They are saying that the  
 651 moose population is going down../  
 652 But down from what time?/ Like when  
 653 they killed all of the .... when  
 654 they almost/ killed all of the  
 655 wolves off, the moose population  
 656 would have gone up really high/...  
 657 and now that it is illegal to kill  
 658 wolves,.... definitely/ the moose  
 659 population is going to go down. If  
 660 we know before,/ when it was only  
 661 native people... They have small  
 662 population densities, so they  
 663 probably/ weren't doing that much  
 664 hunting and trapping... Ahm.. OK.  
 665 Before,/ they both had...before  
 666 when they were just being hunted by  
 667 native people, they both had large  
 668 populations../.. I think what the  
 669 big game hunters want/ is a large  
 670 population, even larger than that  
 671 large population/ .. even higher  
 672 than that large population.../ OK.  
 673 I kind of lost my train of though  
 674 for a second./.. Yeah.. so the



675 moose population was high.. Say it  
 676 was at a value ten,/ and maybe the  
 677 wolf population was at a value of  
 678 two.../ OK. Then when you killed..  
 679 when the wolves went down/... the  
 680 moose went up. So now,/ whereas ten  
 681 was a large population before and  
 682 two was a large population before,/   
 683 now the hunters are used to ...say  
 684 a population of fifteen,/ and they  
 685 would like to stay at fifteen...  
 686 but because now you can kill  
 687 wolves,/ .. You can't kill wolves,  
 688 so wolves are going back up,  
 689 probably to about two, which would  
 690 seem large to them,/ .. and this  
 691 would go down to about ten.... I  
 692 guess what this is coming down to/  
 693 is that you have to ahm../ decide  
 694 between what is more important..  
 695 The economy of this town or/ ...  
 696 having a good moose population and  
 697 having a good wolf population./  
 698 Hum...../  
 699 Declining .... / So I am trying to  
 700 decide what to do... about the  
 701 declining moose population problem.  
 702 / OK. .. OK. From what I have  
 703 interpreted, the declining moose  
 704 population problem/ only presents a  
 705 problem for the town... It seems  
 706 completely logical to me/ .. like  
 707 .. what the town is used to is an  
 708 abnormally large size/ of moose  
 709 population. Ahm... so the declining  
 710 moose population isn't a problem in  
 711 nature... Ahm.. because....  
 712 because/ now it is just returning  
 713 to the way it was before..... more  
 714 or/ less... as long as hunting is  
 715 controlled now, because ../..  
 716 before you just had native people  
 717 hunting... You have.. probably/ the  
 718 native people are still hunting,  
 719 but you have the big game hunters  
 720 that are going in with their/ semi-  
 721 automatic everything and they can  
 722 kill a lot more../.. I would say  
 723 the best way to keep../ the economy  
 724 going for the town ... and.. OK./  
 725 Because , if you have hunters, ..  
 726 and native people/ and wolves..



727 that are killing the moose  
 728 population, It will be lower/ than  
 729 what it was before. So something  
 730 has to change.. If there were no  
 731 hunters,/ then you would just have  
 732 natives and wolves and you would  
 733 just have the same as before./ But  
 734 you are not going to be able to get  
 735 rid of the hunters with out a lot  
 736 of political problems/.... so if  
 737 you maybe put a../.. If you  
 738 permitted a certain level of  
 739 hunting of wolves,/ then the moose  
 740 that would be normally be killed by  
 741 the wolves,/ could be replaced by  
 742 moose that could be shot by  
 743 hunters. So what I would do for  
 744 this/ problem then is .. I would  
 745 say/ you permit a certain number of  
 746 wolves to be killed, ../..... and  
 747 you should also/ put a limit an the  
 748 number of moose/ that could be  
 749 killed in a year. And I guess,/ in  
 750 order to make sure that the  
 751 population is being stable over the  
 752 years../ to make sure you have  
 753 decided on the right numbers of  
 754 moose and wolves that can be  
 755 killed, that you are going to have  
 756 to/ do a census, maybe once every  
 757 three or four years/ to determine  
 758 the populations...  
 759 So just checking back here/..  
 760 ahm... so remote, /..the native  
 761 people... most recently,/ small  
 762 towns, cattle farming...  
 763 Outfitting for big game hunting,  
 764 moose and wolves./... Ahm.. One  
 765 other thing I don't have in my  
 766 answer/ is that if they were killed  
 767 by farmers and there was a lot of  
 768 cattle farming/ in the area....  
 769 ahm../ I guess what I am saying is  
 770 that I don't have as much  
 771 information as I would like to/  
 772 solve this problem because,.... I  
 773 know there is a lot of cattle  
 774 farming,/ .. Well, maybe there is  
 775 not a lot of cattle farming... Yet  
 776 they would have had to clear land  
 777 for the cattle farming/ and I don't  
 778 know if this cleared land is coming

E:info

P:out

12min

I:soln

I:rea

I:soln

V:eval

R:re

13min

V:eval

A:info

Appendices...314

779 into play with the reduction/ in  
 780 the population of wolves and of  
 781 moose./ So, .... If I knew how much  
 782 land was being cleared,/.. or had  
 783 been cleared, I guess I could  
 784 answer a little bit better . Even  
 785 not knowing how/ much land is being  
 786 cleared, ... You can still/...  
 787 using the populations of moose and  
 788 wolves, ahm.. that can be killed/ a  
 789 year...like the quota you set for  
 790 each one... even if it just/ means  
 791 that more wolves could be killed/  
 792 and less moose could be killed and  
 793 that would still bring the  
 794 population back up/.... So then, I  
 795 guess to solve this problem, I  
 796 would say that a quota has to be  
 797 placed/ on the number of wolves ...  
 798 /that can be killed ... Only a  
 799 certain number of wolves can be  
 800 killed. And this is going to have  
 801 to happen on an annual basis./ And  
 802 there has to be a limit on the  
 803 number of moose that can be  
 804 killed../... OK../...  
 805 R: Thanks. OK. What I would like  
 806 you to do first is to describe to  
 807 me as much as you can remember  
 808 about how you solved that problem.  
 809 You have made some notes here that  
 810 might help you...  
 811 P: OK. First thing was I just read  
 812 it over once to get the main facts  
 813 out and then I read it again just  
 814 to get the facts in order and ..  
 815 to.. see if I missed anything.....  
 816 I .. the first thing I noticed was  
 817 the time factor. That before hand  
 818 there had been large populations of  
 819 both ..and that now... and then it  
 820 says.. OK. Before there were large  
 821 populations of both and with the  
 822 large populations of both there  
 823 were hunting and trapping practices  
 824 of the native people. And then I  
 825 noticed that recently... there had  
 826 become towns with cattle farming  
 827 and outfitting for big game  
 828 hunting. So that told me right away  
 829 that there had been a big problem  
 830 with the populations of moose and

A: info

V: eval

14 min.

I: soln

14 min, 35 sec.

R: 1

R: 1 (cond)

R: re

R: re (cond)

A: his

A: his (cond)

831 wolves because ... well just  
 832 because there is a lot of  
 833 habitation up there now. So I  
 834 figured out... Let me see.. no ..It  
 835 goes on saying that the moose and  
 836 wolves have been affected. And that  
 837 the wolves almost went to  
 838 extinction by farmers.... And that  
 839 stuck out really for me because I  
 840 know that once a population is  
 841 driven to extinction it is no  
 842 longer very stable and .. it says,  
 843 there had been a ban placed on wolf  
 844 hunting which is now entering its  
 845 tenth year. So .. ah.. I knew that  
 846 if the wolf population had been  
 847 driven down to an extreme low and  
 848 if there hasn't been anything  
 849 controlling the wolf population now  
 850 for ten years, the population is  
 851 going to be very large and it  
 852 seemed OK ... Once your wolf  
 853 population is increasing, your  
 854 moose population is going to  
 855 increase, ... so .. I just kind of  
 856 ..... waited to see what else was  
 857 coming out of the problem. The wolf  
 858 population appears to have  
 859 increased, which I expected and the  
 860 moose population had decreased, to  
 861 the extent where the hunters are  
 862 going elsewhere to hunt. That told  
 863 me that the town is going to have  
 864 economic difficulties, because  
 865 those hunters are going to bring a  
 866 lot of money into town. So the big  
 867 hunters argue that wolves..... are  
 868 decimating the moose and they claim  
 869 that the most effective way to  
 870 revive the faltering economy is to  
 871 revoke the ban on killing wolves.  
 872 OK. Ahm.. I kind of figured when  
 873 the hunters are saying that you  
 874 have to revoke the ban on killing  
 875 wolves, this made me sceptical of  
 876 the hunters right away because ..  
 877 well normally when people ask for  
 878 things they always ask for more  
 879 that they should .. or more than  
 880 what is logical, so I just went  
 881 back and tried to ... Well I made a  
 882 graph of the populations of moose

E:info

A:info

R:1 R:1(conda)

R:elab

A:info A:info (conda)

R:rep

883 and wolves... as a function of time  
 884 ... It's not really a graph, but I  
 885 am just showing the relation of ...  
 886 the increasing moose population  
 887 when the ... wolf population  
 888 decreases, so that while the town  
 889 has been in existence really they  
 890 have been used to having a higher  
 891 than normal moose population.  
 892 ...Ahm.. So that told me that the  
 893 moose population can decrease to a  
 894 certain extent with out it harming  
 895 the natural equilibrium.. I guess  
 896 what I figured out after ... I was  
 897 trying to figure out all the forces  
 898 acting on the population of moose  
 899 ... because before the town was  
 900 established all that was acting on  
 901 the population of moose to decrease  
 902 it were the native people's hunting  
 903 and .. the wolf population. Then  
 904 for a while, the moose population  
 905 increased a lot I figured because  
 906 the wolf population had  
 907 decreased... The forces acting on  
 908 it ,.. I really didn't care what  
 909 happened in the middle... I was  
 910 just caring what was happening at  
 911 the end because I knew that the  
 912 population was going down  
 913 now...Because the ... equilibrium  
 914 forces acting on this population  
 915 changed. Because in addition to  
 916 having native people and wolves  
 917 acting on the population, you also  
 918 have these big game hunters. So  
 919 realistically, your population of  
 920 moose is going to be lower than  
 921 what I put in my graph... But when  
 922 I was drawing my graph, I was just  
 923 figuring that this is ideally what  
 924 we want to have... we want to have  
 925 the ten. So I worked it out ... a  
 926 function of the forces acting on  
 927 it, and Ahm.. if before you have  
 928 native people plus wolves acting on  
 929 it, ... That has to be equal to  
 930 hunters plus native people plus  
 931 wolves acting on it. .. And  
 932 basically, the native people's  
 933 contribution probably isn't that  
 934 significant .. So you could leave

R:rep (cont.)  
 - construction  
 and use of a  
 diagram

935 the native population the same on  
936 both sides. So what you have to  
937 have is the wolves before balancing  
938 the wolves and hunters after. So  
939 the... Basically, if you decrease  
940 the wolves by a bit, and you  
941 increase the hunters, it will still  
942 equal the wolves...ahm.. from  
943 before . So .. that is the way I  
944 worked it out.....

Isoln

945 R: One thing that really stood out  
946 for me when you started reading  
947 this problem was that you seemed to  
948 cue into a lot more clues in this  
949 problem than the other one. In the  
950 other problem, you underlined about  
951 three major things. You seemed to  
952 notice more details here, even  
953 before you got to the question at  
954 the bottom. Can you tell me a bit  
955 more about that?

956 P: Yeah. Basically because... I am  
957 familiar with this kind of problem.  
958 It's ah... the kind of thing I have  
959 seen in biology for at least the  
960 past two or three years. We have  
961 been doing population dynamics in  
962 a few of my different courses so...  
963 I am used to dealing with  
964 populations of things, and I have  
965 an idea already of how populations  
966 vary and what are the factors that  
967 cause populations to vary and  
968 also... things like.. I didn't  
969 mention it before when I was  
970 telling you how I solved the  
971 problem, but about this cleared  
972 land thing. That caused me  
973 particular anxiety because we have  
974 been talking about that most  
975 recently in my course with \_\_\_\_\_  
976 about land clearing and how it  
977 affects populations. So most of the  
978 facts that are given in here ..  
979 Things like extinction... ahm..  
980 this clearing of land for the  
981 cattle farming and the populations  
982 of .. moose and wolves, a ban on  
983 hunting wolves, .. all of that is a  
984 familiar scenario. It is the kind  
985 of thing that ... you can.. It is  
986 the kind of thing you see as a

R: fam

R: fam (cond)

R: fam (cond)

987 typical case study in an ecology  
 988 textbook for population dynamics.  
 989 So I was a lot more comfortable  
 990 reading this problem than I was the  
 991 last one (laughter).  
 992 R: Am I correct in thinking it  
 993 connected really strongly with  
 994 things you already knew? Was that  
 995 the function that made you  
 996 comfortable?  
 997 P: Yeah , One thing.. the  
 998 decreasing wolf population and  
 999 stuff like that ... that is really  
 1000 familiar to me. I am from the  
 1001 country ... Out where I live there  
 1002 used to be a lot of wolves but now,  
 1003 there is no place for them to live,  
 1004 everything is farmland. So it is  
 1005 not...You have to have a special  
 1006 permit to hunt a wolf down and  
 1007 stuff like that. But... I don't  
 1008 know if I am answering the  
 1009 question.  
 1010 R: Yes you are, I think you are  
 1011 telling me that you were  
 1012 comfortable with the question  
 1013 because it connected with things  
 1014 you knew. And it is not just  
 1015 textbook knowledge, but you own  
 1016 life experiences that it related  
 1017 to. Is that right?  
 1018 P: Yeah.. and almost hunted to  
 1019 extinction by farmers.. and  
 1020 clearing land. That is why the  
 1021 cleared land stuck out for me.  
 1022 Because this was in remote northern  
 1023 British Columbia. So I don't know  
 1024 how much land they could have  
 1025 cleared. There would be really  
 1026 rough terrain, a lot of it might  
 1027 not be appropriate for cattle  
 1028 farming, so I didn't know the  
 1029 extent of the cleared land and that  
 1030 really was difficult because if it  
 1031 is extensively cleared, then ...  
 1032 well then I am missing key  
 1033 information to solve the problem  
 1034 because then your moose and your  
 1035 wolf populations are going to be  
 1036 severely affected. So .. the cattle  
 1037 farming.. like in our area.. almost  
 1038 all the land has been cleared, ...

R:fam (cond)

R:fam

E:info

A:info

1039 there is probably.. there used to  
 1040 be a law that for every hundred  
 1041 acres of cleared land, there had to  
 1042 be one acre of forested land, but  
 1043 they have even revoked that now....  
 1044 So I know how clearing land can  
 1045 have an effect on the wolf  
 1046 population because it had a really  
 1047 major one in our area. It is kind  
 1048 of interesting that this problem  
 1049 would have wolves in it at all,  
 1050 because I have been thinking about  
 1051 them recently back in our area. In  
 1052 class we have been talking about  
 1053 things they perceive as bad even if  
 1054 they do not pose a threat to them  
 1055 and I know if there was a wolf  
 1056 hanging around our place, I would  
 1057 want it to be shot... And I have  
 1058 been thinking about wolves  
 1059 recently... that it's difficult to  
 1060 practice what you preach sometimes.  
 1061 (Laughter).  
 1062 R: One thing that I would like to  
 1063 ask you about is that in both  
 1064 problems, you elaborated some  
 1065 meaning. You just didn't use the  
 1066 words in the problem. You  
 1067 translated them and linked the  
 1068 meaning and made it bigger for  
 1069 yourself... I would like to know  
 1070 two things: If that is important  
 1071 and exactly how you use it.  
 1072 P: OK. Ahm... I probably .. I think  
 1073 it is important. I like to .. I  
 1074 guess through years of taking  
 1075 courses where I don't see any  
 1076 application of anything to real  
 1077 life, ... I like to feel that what  
 1078 I am doing is meaningful. So if I  
 1079 can extrapolate the circumstances,  
 1080 or if I can make it seem more real  
 1081 .. something that could happen in  
 1082 the real world,... It makes the  
 1083 problem seem first of all more  
 1084 feasible... It is not something  
 1085 that is just working on text book  
 1086 conditions. It is something that is  
 1087 really happening. Ahm... It makes  
 1088 it seem to me that the problem is  
 1089 more worthwhile solving ... And I  
 1090 guess also, getting back to the



Emfo

R: elab

R:elab (cond)

R: int

R: int (cond)

1091 other problem where I created a  
 1092 mental image for that problem... I  
 1093 did the same for this too.. And  
 1094 it's.. I guess extrapolating helps  
 1095 me be more in the problem... I can  
 1096 ... really ... It really does help  
 1097 me feel like the problem is  
 1098 surrounding me and I can see it  
 1099 from all sides.  
 1100 R: Do you elaborate more under some  
 1101 kinds of conditions than others?  
 1102 You mentioned specifically text  
 1103 book problems...to give them a  
 1104 basis in reality.  
 1105 P: I think if I am not pressed for  
 1106 time I put my self more into the  
 1107 problem. If I were in a test  
 1108 situation, and I had to do  
 1109 something really under pressure....  
 1110 I think those things would be going  
 1111 through my mind and I don't know if  
 1112 I would have as much opportunity to  
 1113 put myself in the exact situation.  
 1114 I think I would tend to be more  
 1115 reactionary. .... If I were  
 1116 pressed for time, I would still  
 1117 have to read it through twice and  
 1118 pick out the important points .. I  
 1119 would not have as much time to  
 1120 spend being in the problem... I  
 1121 might just have to do the graph  
 1122 more quickly... But still, it is a  
 1123 kind of visualization, but I don't  
 1124 think I would involve myself as  
 1125 much in the problem...  
 1126 R: Is interest in the problem a  
 1127 critical factor in how you solve  
 1128 the problem?  
 1129 P: .I think it probably is, because  
 1130 .. Well... Not necessarily interest  
 1131 in the problem.. because I am  
 1132 interested in this problem, but it  
 1133 I am taking a course, and I have a  
 1134 problem.. I can tell you from my  
 1135 physics course, that I am not at  
 1136 all interested in it ... (laughs).  
 1137 But I can still solve the problem..  
 1138 Interest is important for me to  
 1139 feel that I am learning something  
 1140 .. To feel that the problem is  
 1141 useful, but I could very  
 1142 mechanically solve a problem with

Rielab

Rielab (cond)

Rielab(cond)

General  
Strategy  
Knowledge

Rielab

Rielab(cond)

Rint

Rint (cond)

1143 out any interest.  
 1144 R: I am trying to make sure I am  
 1145 interpreting what you are saying  
 1146 correctly. Are you saying that in  
 1147 physics you wouldn't work as hard  
 1148 to put yourself in a problem the  
 1149 way that you have put yourself in  
 1150 these problems?  
 1151 P: Definitely not. Physics for me  
 1152 is something that I can't.. the  
 1153 stuff we have been doing most  
 1154 recently is something I can't ....  
 1155 well maybe this is something that  
 1156 will be of interest to you because  
 1157 I can't put myself in it at all and  
 1158 I am having major hang ups with it.  
 1159 I can't conceive magnetism... I  
 1160 can't imagine ...  
 1161 R: Do you mean visually ....  
 1162 P: I guess visually but other  
 1163 things too... I can picture gravity  
 1164 or mechanics problems, but not  
 1165 magnetism... I really didn't do  
 1166 well on my midterm.. even if it  
 1167 were a different aspect of  
 1168 physics.... Motivation is a key  
 1169 point. If I look at it from the  
 1170 point of view that ... I never am  
 1171 going to use magnetism again in my  
 1172 life. It really doesn't really have  
 1173 any bearing on what I am doing. It  
 1174 is the only option course that  
 1175 would fit into my schedule. I am  
 1176 really not interested. There are  
 1177 all of these formulas and you have  
 1178 to figure out how this one fits  
 1179 with that one and you have all  
 1180 these different formulas... that go  
 1181 together... In Physics, there is  
 1182 only one way to solve a problem,  
 1183 more or less... It seems to be  
 1184 entirely linear. Biology seems..  
 1185 There is a lot more different ways  
 1186 you can solve things.. It is more  
 1187 ....susceptible to individual  
 1188 interpretations...my own perception  
 1189 .... Physics is not the way I am  
 1190 used to thinking... I enjoy solving  
 1191 some of the problems in physics  
 1192 because it is such a foreign way  
 1193 for me to solve problems that it  
 1194 ...It's kind of refreshing... When

R:elab

R:elab (cond)

R:elab

R:elab (cond)

R:int

R:int (cond)

Biology vs. Physics

Appendices...322

1195 I can get the right  
 1196 answer..(laughs) I still find  
 1197 physics to be pretty frustrating...  
 1198 R: Can you put your finger on any  
 1199 more differences between solving  
 1200 problems in biology and physics?  
 1201 P: ...Ahm.. Well probably one of  
 1202 the things is that I don't have as  
 1203 wide a basis in physics as I do in  
 1204 biology. This is only my third  
 1205 university level physics course....  
 1206 The differences.... are first of  
 1207 all in my own past experience  
 1208 because ... I guess if you look you  
 1209 can observe physics anywhere... it  
 1210 is not something I take note of as  
 1211 much as I take note of biological  
 1212 principles..like.... Listening to  
 1213 the news.. I guess biology is a lot  
 1214 more in the news. It is something  
 1215 that is on a world events kind of  
 1216 scale..... To me.. I don't really  
 1217 see ... I guess this goes back to  
 1218 the application in the real world  
 1219 part. .. I don't really see me  
 1220 using physics.. It doesn't seem to  
 1221 be applicable.... useful.. Whereas  
 1222 biology .. I can see world problems  
 1223 where it would be useful to have  
 1224 biological principles to solve it.  
 1225 R: . . . OK. Let's see what else I  
 1226 would like to ask you. One of the  
 1227 obvious things here was that you  
 1228 had a lot more information to bring  
 1229 to this problem. In some ways,  
 1230 that's a complication. When you  
 1231 have a lot of information, you have  
 1232 to sort it out. Do you have any  
 1233 notion of deciding what information  
 1234 from your own knowledge you were  
 1235 going to use here?  
 1236 P: Ahm.. I guess maybe.. It is just  
 1237 from seeing this kind of problem  
 1238 solved before... knowing how the  
 1239 system works or whatever.... I ...  
 1240 have an understanding of how  
 1241 population dynamics works, so... I  
 1242 just took things that I know are  
 1243 important to population dynamics...  
 1244 and brought it in . Things that I  
 1245 have read or I used in solving  
 1246 another problem... Because maybe we



General  
 Strategy  
 Knowledge

R: fam      R: fam (cond)

R: int      R: int (cond)

R: fam      R: fam (cond)

E: info      E: info (cond)

Appendices...323

1247 saw it in a lab experiment or  
1248 something. ...  
1249 R: So it was really experience that  
1250 allowed you to map onto what was  
1251 important? You didn't have to  
1252 consciously search a lot?  
1253 P: Yeah.. Yeah.  
1254 R: You kind of did that in the  
1255 first problem.. Remember when you  
1256 were deciding on education and then  
1257 you remembered a program in your  
1258 old highschool and it gave you more  
1259 confidence in your recommendation..

1260 P: Yeah... and it was that way for  
1261 intermittent residents of half way  
1262 houses. I was typing up a paper for  
1263 my brother about two weeks ago  
1264 where he was talking about this  
1265 half way house that there is in  
1266 \_\_\_\_\_ and it helped to have to  
1267 have that personal experience...  
1268 but I certainly don't have all the  
1269 psychology involved.. ...

1270 R: In both of your problems, but in  
1271 this problem more... you answered  
1272 the question and then you checked  
1273 back to see if you had taken  
1274 everything into account .. Is that  
1275 an important part of your problem  
1276 solving?

1277 P:..Definitely, because... Like  
1278 again, I could have missed some  
1279 very key point... Ahm...

1280 Definitely. because suppose.. I  
1281 don't know... what I could have  
1282 missed , but suppose there was some  
1283 factor that was relating the two  
1284 populations together... That I  
1285 didn't know.. that would entirely  
1286 change the solution. If I don't go  
1287 back and check... I could very well  
1288 have missed something. I only read  
1289 it through .. two times before I  
1290 started putting everything together  
1291 ... The first time I read it.. I  
1292 just skipped over this part about  
1293 native people... I didn't even see  
1294 it... So I could have missed  
1295 something else. I always like to go  
1296 back and plug everything back in  
1297 and make sure it is the same way

E:inf

E:info (cond)

V:eval

V:eval(cond)

R:1

R:1 (cond)

V:eval

V:eval (cond)

1298 and just check my answer... I don't  
 1299 want to get a wrong answer just  
 1300 because I read wrong.  
 1301 R: The other thing I would like to  
 1302 ask you before we leave this  
 1303 particular problem... is what, in  
 1304 your estimation are the most  
 1305 important things you did when you  
 1306 solved that problem in terms of  
 1307 being able to reach a solution?  
 1308 P: .... I think one of the most  
 1309 important things was realizing that  
 1310 ... populations of both moose and  
 1311 wolves are variable as a function  
 1312 of time... and that the two are  
 1313 related to each other... it is a  
 1314 predator \_ prey relationship... So  
 1315 probably this graph was one of the  
 1316 most important things... And the  
 1317 second most important thing was  
 1318 realizing ... that .. why was it  
 1319 like that? How did it change and  
 1320 how can we get at a sustainable  
 1321 level? If I could have drawn a  
 1322 diagram of the forces like if it  
 1323 had been a biomechanics problem....  
 1324 The sum of the forces kind of  
 1325 thing... So that is really  
 1326 important in solving it. And... I  
 1327 think one of the other important  
 1328 things is just.. Making sure..  
 1329 reading through ..and being assured  
 1330 that the rest of the problem is  
 1331 coherent with what I have  
 1332 developed... Like .... .. even  
 1333 though the establishment of the  
 1334 town... is not critical for solving  
 1335 the problem.... but knowing that  
 1336 once the town was established, this  
 1337 process and that process happened  
 1338 and that follows .... there was a  
 1339 logical sequence of events and I  
 1340 was just making sure that all rest  
 1341 of the facts in the problem go  
 1342 along with what I am thinking... A  
 1343 professor could really mix you up  
 1344 if ... the problem is... everything  
 1345 is coherent except for one  
 1346 phrase... which just doesn't fit  
 1347 into the problem. It just destroys  
 1348 the flowing nature of the problem..  
 1349 the way that everything runs

V:eval / R:re  
 A:info  
 R:rep R:rep (cond)  
 A:info  
 R:rep  
 V:eval V:eval (cond)  
 A:info  
 V:eval V:eval (cond)  
 A:info A:info (cond)

1350 together.. To have something that  
 1351 doesn't fit in.. I throws  
 1352 everything back into jeopardy.. OK.  
 1353 Why doesn't this fact fit? Did I  
 1354 miss something else? Is the entire  
 1355 relationship wrong. It is important  
 1356 that everything in the problem goes  
 1357 together....  
 1358 R: And you work at making a  
 1359 coherent conceptualization of the  
 1360 problem... You don't keep all the  
 1361 elements of the problem separate,  
 1362 but allow them to interact....and  
 1363 elaborate what each of them means  
 1364 in the total context of the  
 1365 problem?...  
 1366 P: Um-hum. Yeah . It's.. Sometimes,  
 1367 if you pay enough attention to the  
 1368 problem and if you .... have a good  
 1369 perception of the facts that are  
 1370 being given, sometimes when you are  
 1371 answering the problem, you  
 1372 understand why the professor has  
 1373 given you this particular fact...  
 1374 that they want you to use it in the  
 1375 answer.. In highschool I used to be  
 1376 really good a knowing what the  
 1377 teacher wanted from the way the  
 1378 question was asked...Even in first  
 1379 and second year.. From what had  
 1380 been taught in a course... I could  
 1381 make logical deductions about what  
 1382 the problems on the exam would  
 1383 be... Putting myself in the  
 1384 professor's shoes a bit.. You want  
 1385 to answer the problem the way that  
 1386 you are going to get marks, so that  
 1387 if you can get from the problem ...  
 1388 what the professor wants, obviously  
 1389 you are going to have a better  
 1390 answer.  
 1391 R: So would you say that is an  
 1392 important influence in how you  
 1393 approach a problem?  
 1394 P: Not if I am pressed for time...  
 1395 In highschool I always had a lot  
 1396 more time to answer problems than I  
 1397 have now.... (laughs). So maybe it  
 1398 is not as much of a .. Not as much  
 1399 involved in my problem solving  
 1400 now.. but in preparation for an  
 1401 exam... I try and figure out what

V:eval

V:eval (cond)

A:link

A:info

A:info (cond)

A:per

A:per (cond)

General  
 Strategy  
 Knowledge

General  
 Strategy  
 Knowledge

1402 questions are going to be asked....  
 1403 and stuff like that.. You know how  
 1404 I was saying before if one phrase  
 1405 doesn't doesn't fit into the rest  
 1406 of the problem it would make me  
 1407 feel uncomfortable... ? This cattle  
 1408 farming made me feel uncomfortable  
 1409 ... until I figured it could be  
 1410 included in the force diagram in  
 1411 the end... One other force to be  
 1412 compensated for... That worried me,  
 1413 so I went back through and checked  
 1414 ....  
 1415 R: I have some more general  
 1416 questions. ... Just relating to  
 1417 what you were just talking about ..  
 1418 You talked about how being  
 1419 interested in a problem is  
 1420 important to how you solve it. Can  
 1421 you think of some other things that  
 1422 might influence how you solve  
 1423 problems...?  
 1424 P: .. Yes... In an exam situation,  
 1425 often ... often the kind of problem  
 1426 you are getting is something you  
 1427 have already seen in class... It  
 1428 might have a little bit of a twist  
 1429 to it, but often the pattern of  
 1430 thinking is already there. ... If I  
 1431 have solved the problem before,  
 1432 when I go to solve it again, .. I  
 1433 have already understood it once, so  
 1434 it is easier to go through and  
 1435 maybe.. that's ...definitely good  
 1436 because when you are pressed for  
 1437 time.. You don't have to take the  
 1438 time to consider.... the  
 1439 implications of the problem or how  
 1440 the problem can be meaningful .. We  
 1441 have already done that in class...  
 1442 When the professor is solving it  
 1443 you solve along and think of the  
 1444 applications for it or how the  
 1445 problem is useful .. So .. on an  
 1446 exam, when I come to a problem that  
 1447 I am familiar with, it's easier for  
 1448 me to go through it quickly under  
 1449 pressure.... So I guess it would  
 1450 take me longer on an exam.. I guess  
 1451 naturally that I have never seen  
 1452 before .. I guess part of that is I  
 1453 don't understand how it can be

A: info  
 A: link  
 R: und      R: und (cond)  
 E: agy      E: agy (cond)  
 General Strategy Knowledge  
 Strategy Acquisition Knowledge  
 R: fam      R: fam (cond)  
 R: int      R: int (cond)

1454 applicable in the real world. If I  
 1455 am solving a problem just with  
 1456 friends, .. I am working in a group  
 1457 to solve a problem .. when you are  
 1458 not under pressure, you can take  
 1459 more variables into consideration,  
 1460 you can .... analyze more... in a  
 1461 more complete way , in a more  
 1462 thorough way.. I guess what I am  
 1463 saying is when you have a lot of  
 1464 time you can consider alternative  
 1465 approaches to solving a problem,  
 1466 whereas when you are doing a  
 1467 question and you are pressed for  
 1468 time, and you have one answer that  
 1469 maybe seems obvious to you, or even  
 1470 if it isn't obvious.. if the  
 1471 problem works, then you don't need  
 1472 to search an alternative solution  
 1473 ... because you know as long as you  
 1474 get a right answer, and your  
 1475 thinking is logical, then you are  
 1476 going to get the marks. There could  
 1477 be a completely different way to  
 1478 solve the problem.... I guess in an  
 1479 exam situation, the information you  
 1480 are given is limited compared to a  
 1481 real world kind of problem where  
 1482 there are so many things you can  
 1483 bring into it... I'd say the  
 1484 approach would be different...  
 1485 R: Do you like solving problems ?  
 1486 Do you feel comfortable doing it?  
 1487 P: I feel comfortable solving  
 1488 problems... I like solving physics  
 1489 problems, when it is something that  
 1490 I can conceptualize. We are into a  
 1491 part of the course now that ..thank  
 1492 goodness.. I do understand, . this  
 1493 part really does interest me and I  
 1494 do want to understand it .. I have  
 1495 lost track....  
 1496 R: I was asking you if you liked to  
 1497 solve problems...  
 1498 P: I feel comfortable. On an exam  
 1499 situation, I would rather be posed  
 1500 a problem than, say an essay  
 1501 question. R: So you have confidence  
 1502 in your strategies?  
 1503 P: I think so .. Yes.  
 1504 R: You clearly have some good  
 1505 problem solving strategies and good

General  
 Strategy  
 Knowledge

Print

1506 attitudes about problem solving  
 1507 that you have learned somewhere  
 1508 along the way... Can you think  
 1509 back.. If you were going to give me  
 1510 advice on what kinds of activities  
 1511 and experiences would be good for  
 1512 students to help them learn about  
 1513 problem solving, What would you  
 1514 recommend? What kinds of  
 1515 experiences have been important to  
 1516 you?  
 1517 P: OK. .... Well, I think probably  
 1518 .... most of my problem solving  
 1519 skills probably go back a long way,  
 1520 right to public school. I had a  
 1521 wonderful teacher in public school  
 1522 and she was so good at making our  
 1523 class not just... .. be satisfied  
 1524 with the minimum amount that you  
 1525 could do, but ... to do more.. Our  
 1526 classes were always quite an  
 1527 advanced group of students for our  
 1528 age... Probably one of the most  
 1529 important things for making....  
 1530 problem solving skills in a student  
 1531 would be to start at a young age  
 1532 and to do it .. When they are  
 1533 solving problems to show the  
 1534 application that it can have ...  
 1535 And always to feel that what you  
 1536 are doing is important... And  
 1537 not... oh well, because it will be  
 1538 important someday  
 1539 It will be important now. I  
 1540 remember feeling frustrated because  
 1541 some of the things we were doing in  
 1542 some of the highschool math didn't  
 1543 seem applicable. In first year  
 1544 calculus ... I think that making  
 1545 someone feel that what they are  
 1546 solving is important ... is  
 1547 probably a key element.  
 1548 R: Are there certain kinds of  
 1549 activities that you did or subjects  
 1550 that you took that were useful in  
 1551 developing a knowledge of problem  
 1552 solving?  
 1553 P: Let me think here..... ..  
 1554 .....  
 1555 I kind of feel that my earliest  
 1556 problem solving skills definitely  
 1557 come from math... The math problems

Strategy  
 Acquisition  
 Knowledge

R: int

Strategy  
 Acquisition  
 Knowledge

1558 that I did when I was younger. ...  
 1559 I don't think I could say it comes  
 1560 exclusively from math. I remember  
 1561 when I was in grade five, we had a  
 1562 newspaper project and that was a  
 1563 different kind of problem solving  
 1564 ... It was far more creative kind  
 1565 of problem solving... and ... I  
 1566 think probably... a variety of  
 1567 problem solving skills is  
 1568 important, but... I think that I  
 1569 would have felt inundated if there  
 1570 were too many different kinds  
 1571 coming at me all at once... Another  
 1572 really important part of problem  
 1573 solving for us was ... Our teacher  
 1574 was really hype on this and we ...  
 1575 I think that we were really hype on  
 1576 it because she was.. was  
 1577 grammar.... Plain English grammar  
 1578 .... She had a really great way of  
 1579 teaching grammar and it was a kind  
 1580 of problem solving . She started  
 1581 with a simple kind of problem  
 1582 solving and added variety.. I think  
 1583 that is a good way....  
 1584 R: What about your university  
 1585 experience, do you think it has  
 1586 enhanced your ability to solve  
 1587 problems?  
 1588 P: I think so. It has definitely  
 1589 built up my background knowledge.  
 1590 So I would definitely... Given a  
 1591 biology problem now, I have such a  
 1592 vast knowledge behind me that I  
 1593 would be able to ..solve it,  
 1594 probably based a lot on my back  
 1595 ground knowledge. But even if I  
 1596 were posed some kind of strange  
 1597 problem, I have developed problem  
 1598 solving skills that are valuable  
 1599 even if I don't have such a great  
 1600 background knowledge about the  
 1601 specific topic. I guess .. the way  
 1602 that I have been taught to  
 1603 interpret .... a problem when it is  
 1604 posed and .. the way that I can..  
 1605 when I am reading it .. put things  
 1606 into perspective ... I think that  
 1607 having learned that through my  
 1608 biology problems and other problems  
 1609 I have been presented with ...I ..

Strategy  
 Acquisition  
 Knowledge

General  
 Strategy  
 Knowledge

Strategy  
 Acquisition  
 Knowledge

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1610 kind of have a bag of tricks for  
1611 solving problems.  
1612 R: Have you taught yourself that  
1613 bag of tricks, just by reflecting  
1614 on your problem solving?  
1615 P: I think that I would have to say  
1616 it is something I have almost  
1617 entirely developed myself, because  
1618 professors don't spend a lot of  
1619 time teaching you how to go about  
1620 it. It is something that you learn  
1621 yourself through working at home or  
1622 your own individual reading .....  
1623 through your own frustration, when  
1624 you are solving a problem. It is  
1625 clearly something that I have  
1626 developed myself.  
1627 R: Do you look back on how you  
1628 solved a problem?  
1629 P: I think it is more of a  
1630 subconscious level. Let's say if I  
1631 have solved a problem and I have  
1632 used a certain ... flow chart for  
1633 the solution .. When I see  
1634 something that seems familiar, I  
1635 might not remember the original  
1636 problem, but I remember how I  
1637 organized my thoughts and the data  
1638 from the problem to be able to  
1639 arrive at the solution.  
1640 R: So there would be cues in the  
1641 new problem like there were cues  
1642 here that helped you think of  
1643 strategies like making a graph of  
1644 the population changes... You  
1645 hadn't solved this exact problem  
1646 before but you had experienced some  
1647 population dynamics problems....?  
1648 P: Yeah. Um-hum.....  
1649 R: Well, thank you very much for  
1650 this. This data will be good for my  
1651 study.

||| Strategy  
Acquisition  
Knowledge

||| Strategy  
Acquisition  
Knowledge

||| General  
Strategy  
Knowledge

R: fam

R: fam (cond)



Characteristics of Notes	Task						
	BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	E	D	T
● a list of problem components	T1	4	6	3	4		
	T2	4	4	2	5		
● a list of solution components	T1	2	5	1	3	B	
	T2	6	7	2	5	PS	P
● an elaboration of the solution	T1	1	1	0	1		BP
	T2	1	2	0	2		

## FUNCTION

● represent the problem	T1	4	6	2	4		
	T2	4	4	2	5	PS	
● plan the solution	T1	3	5	1	3		
	T2	6	7	1	5	PS	P
● elaborate the solution	T1	1	2	0	2		BP
	T2	2	2	0	2		
● evaluate the solution	T1	1	3	0	2		
	T2	5	5	2	3	P	BP

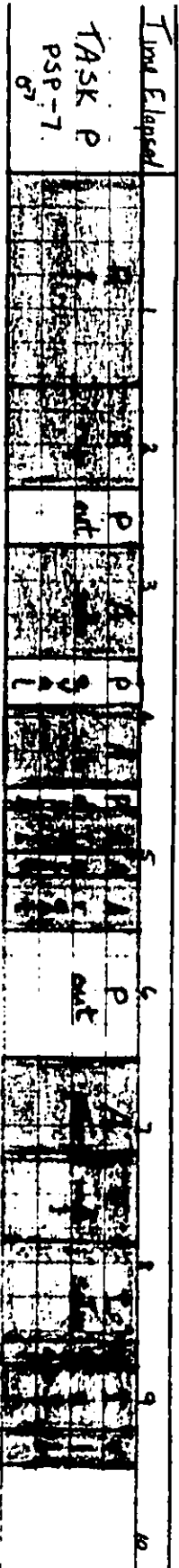
Note: A pattern is discernable where there is a frequency difference of three or more cases across expertise (E), domains (D) and tasks (T).

B = biology    PS = political science    P = professors    S = students

APPENDIX K

**SOLVERS' RATINGS OF EXPERIMENTAL TASKS  
ON FOUR CRITERIA OF ILL-STRUCTUREDNESS**

ILL-STRUCTUREDNESS CRITERIA	LEVEL OF AGREEMENT	GROUP							
		BP (n=9)		BS (n=9)		PSP (n=9)		PSS (n=9)	
		T1	T2	T1	T2	T1	T2	T1	T2
1. This problem does not have a single, correct response	agree	8	7	8	9	5	7	6	7
	ambivalent	1	1	1	0	3	1	0	0
	disagree	0	1	0	0	1	1	3	2
2. The solution of this problem requires the solver to contribute information	agree	8	7	6	8	7	7	8	9
	ambivalent	0	0	2	1	1	1	0	0
	disagree	1	2	1	0	1	1	1	0
3. There is more than one possible series of problem solving steps which could result in a solution	agree	8	7	8	9	8	8	7	7
	ambivalent	1	1	1	0	1	0	1	2
	disagree	0	1	0	0	0	1	1	0
4. The solver can make decisions about the relative importance and roles of problem components	agree	8	7	8	9	9	9	8	9
	ambivalent	0	0	0	0	0	0	0	0
	disagree	1	2	1	0	0	0	1	0



Colour Codes:

- R: = Green
- A: = red
- E: = grey
- P: = yellow
- I: = purple
- V: = brown

**APPENDIX M: Mean Percentages of Solving Time Devoted to Global and Specific Strategies**

- Table M-1 Global Strategies**
- Table M-2 Specific READ Strategies**
- Table M-3 Specific ANALYZE Strategies**
- Table M-4 Specific EXPLORE Strategies**
- Table M-5 Specific PLAN Strategies**
- Table M-6 Specific IMPLEMENT and VERIFY Strategies**

TABLE M-1

Mean Percentage of Solving Time Devoted to Each  
GLOBAL STRATEGY

Global Strategy	Task	Mean Percentage of Solving Time for Each Group				Pattern(s)		
		BP	BS	PSP	PSS	E	D	T
READ	T1	35	42	38	48	B (T1)	P (T2)	PSP
	T2	36	39	26	38	PS (T1,2)	S (T1)	PSS
ANALYZE	T1	22	14	20	10	B (T1)		BP
	T2	15	11	18	8	PS (T1,2)		
EXPLORE	T1	7	5	5	6		P (T2)	PSP
	T2	3	5	11	10		S (T2)	
PLAN	T1	25	12	20	19	B (T1)	P (T1)	BS
	T2	25	24	22	22		S (T1)	
IMPLEMENT	T1	10	22	12	12	B (T1)	S (T1)	BP
	T2	15	14	16	15			BS
VERIFY	T1	1	4	6	6		P (T1)	BP
	T2	6	6	8	7			

**Note:** Patterns are discernable where there are differences of 5% or more between mean percentages across expertise (E), Domain (D) or tasks (T).

B = biology    PS = political science    P = professors    S = students  
 T1 = Task 1    T2 = Task 2

TABLE M-2

Mean Percentage of Solving Time Devoted to  
**SPECIFIC READ STRATEGIES**

Specific READ Strategy	Task	Group					Pattern(s)	
		BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	E	D	T
R:l - first reading	T1	19	17	20	21	B (T2)	S (T1,2)	BP PSP
	T2	16	12	16	17			BS PSS
R:re - re-reading	T1	3	13	4	7	B (T1,2)	S (T1,2)	PSP
	T2	4	14	1	4	PS (T1,2)	P (T2)	PSS
R:imp - monitor important information	T1	4	5	2	4	PS (T2)	P (T2)	
	T2	5	4	1	5			
R:elab - elaborate meaning	T1	3	2	3	5	PS (T2)	S (T1,2)	
	T2	3	3	1	6			
R:diff - monitor difficulty	T1	0	1	2	1			
	T2	1	1	1	1			
R:fam - monitor familiarity	T1	2	1	1	1			
	T2	2	0	3	1			
R:und - monitor understanding	T1	0	1	2	3			
	T2	0	2	0	2			
R:int - monitor interest	T1	0	0	1	0			
	T2	0	0	1	1			

TABLE M-2

Specific READ Strategy	Task	Group					Pattern(s)	
		BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	E	D	T
R:rep - generate a representation	T1	5	3	3	6	PS (T1)	S (T1)	PSS
	T2	4	3	2	1			

Note: Patterns are discernable where there are differences of 3% or more between groups across expertise (E), domains (D) or tasks (T)

B = biology    P = professor    PS = political science    S = student

TABLE M-3

Mean Percentage of Solving Time Devoted to  
SPECIFIC ANALYZE STRATEGIES

Specific ANALYZE Strategy	Task	Group					Pattern(s)		
		BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	E	D	T	
A:info - analyze information	T1	9	8	11	6		PS (T1,2)	P (T2)	BP PSP
	T2	3	2	6	3				BS PSS
A:sub - identify sub-problems	T1	3	1	0	1			P (T1)	PSP
	T2	3	2	3	1				
A:link - identify links	T1	1	0	0	0				
	T2	1	1	1	1				
A:per - monitor perspective	T1	6	3	4	2		B (T1)		BP
	T2	3	2	4	1		PS (T2)		
A:bias - monitor bias	T1	2	2	2	1				
	T2	0	1	1	1				
A:assm - monitor assumptions	T1	1	0	1	0				
	T2	2	1	1	1				
A:his - historical analysis	T1	1	0	0	0				
	T2	1	0	0	0				

TABLE M-3

Specific ANALYZE Strategy	Task	Group				Pattern(s)		
		BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	E	D	T
A:start - identify a starting point	T1	0	0	0	0			
	T2	0	0	1	0			
A:rest - restructure the problem	T1	0	1	2	1			
	T2	0	0	1	0			

Note: Patterns are discernable when there are differences of 3% or more between groups across expertise (E), domains (D) or tasks (T)

B = biology    P = professor    PS = political science    S = student

TABLE M-4

Mean Percentage of Solving Time Devoted to  
EXPLORE STRATEGIES

Specific EXPLORE Strategy	Task	Group					Pattern(s)		
		BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	E	D	T	
E:sour - explore sources of information	T1	0	0	1	1		PS (T2)	S (T2)	
	T2	1	0	0	3				
E:info - explore available information	T1	5	5	5	3		B (T2)	P (T2)	BP, PSP
	T2	1	5	8	5		PS (T2)		
E:sel - select relevant information	T1	1	0	0	0				
	T2	0	0	0	0				
E:agy - explore analogies	T1	1	0	0	1				
	T2	0	0	1	1				

Note: Patterns are discernable where there are differences of 3% or more between groups across expertise (E), domains (D) or tasks (T)

B = biology    P = professor    PS = political science    S = student

TABLE M-5

Mean Percentage of Solving Time Devoted to  
PLAN STRATEGIES

Specific PLAN Strategy	Task	Group				Pattern(s)		
		BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)	E	D	T
P:out - outline a plan	T1	16	9	12	13	B (T1)	P (T1,2)	BS, PSS
	T2	14	14	11	18	PS (T2)	S (T1,2)	
P:eval - evaluate plan(s)	T1	4	2	1	3	PS (T2)	P (T1)	BS PSP
	T2	8	7	6	3		S (T2)	BP
P:alt - consider alternative plans	T1	0	0	1	2			
	T2	0	1	2	0			
P:mod - modify the plan	T1	3	0	3	0	B (T1)		PSP
	T2	1	0	0	0	PS (T1)		
P:diff - monitor difficulty	T1	2	1	2	0	PS (T2)		
	T2	2	2	3	0			

Note: Patterns are discernable where there are differences of 3% or more between groups across expertise (E), domains (D) or tasks (T)

B = biology    P = professor    PS = political science    S = student

Mean Percentage of Solving Time Devoted to  
IMPLEMENT AND VERIFY STRATEGIES

Specific Strategy	Task	Group				E	Pattern(s)	
		BP (n=9)	BS (n=9)	PSP (n=9)	PSS (n=9)		D	T
<b>IMPLEMENT</b>								
I:soln - make a solution statement	T1	10	19	11	11	B (T1)	S (T1)	BP PSP
	T2	13	14	14	13			BS
I:rea - give reasons	T1	0	3	1	3	B (T1)	S (T1)	
	T2	2	1	2	2			
<b>VERIFY</b>								
V:eval - evaluate the solution	T1	0	3	2	3	B (T1)		BP, PSP
	T2	4	4	5	5			
V:lim - evaluate solution limits	T1	1	1	2	2			
	T2	2	1	2	2			
V:alt - consider alternative solutions	T1	0	0	0	1			
	T2	0	1	0	0			

Note: Patterns are discernable where there are differences of 3% or more between groups across expertise (E), domains (D) or tasks (T)

B = biology    P = professor    PS = political science    S = student