METACOGNITIVE BELIEFS AND EXPERIENCES: BELIEFS, PREDICTIONS, MONITORING AND EVALUATIONS IN WELL-DEFINED AND INSIGHT PROBLEM SOLVING

Thesis presented in partial fulfillment
of the requirements for the degree
of Master of Arts in Psychology
at Massey University,
Palmerston North,
New Zealand

SHANE PALMER

2002

ACKNOWLEDGEMENTS

The process of completing my research and thesis has provided its share of challenges, difficulties, and rewards. Although there is only one name on the cover, many people have been critical in providing their assistance and support to me during this project. I would like to offer my sincerest appreciation to you all:

First and foremost, to my primary supervisor Dr. Julie Bunnell, who, despite new responsibilities of her own, willingly and warmly provided her time and expertise in all aspects of my thesis, particularly on the conceptual and analytic issues, the administrative organisation (including help in obtaining the PSI, parking permits, research space and much else) and proofing of the write-up when it finally arrived! I am especially appreciative of Julie's understanding and compassion, and for her encouragement at all, including the most difficult, times.

Secondly, to my secondary supervisor Dr. John Podd, who provided much-appreciated back-up, and whose availability to provide help whenever needed was invaluable. John was particularly helpful in dealing with the analytic details, and in helping me to consider more clearly some of the conceptual issues that arose.

To other members of the School of Psychology: especially Harvey Jones for his technical and programming expertise in intuitively designing the computer program that was the basis for everything! Also, Malcolm Louden for his calculation of the angular warmth measures. And Michael Donnelly for administrative support in procuring valuable research space and allowing me to pay participants!

There are a host of friends and fellow students who I thank for both intellectual and emotional support: Steve Stewart-Williams (our deep psychological and philosophical chats were enjoyable *and* useful!), and fellow Masters students along the way, Ben Heaven (having fun debating merits of quant. vs. qual., and a genuine good bloke!), Sharon Leadbetter (a true friend and inspiration since first year!), Toni Hyde, Nicola Addis, everyone hanging out in the grad room, and to all my friends – you know who you are!

My research would not have been possible without the participants who generously gave their time and concentration in taking part – despite being baffled by many problems! I thank you all for your willingness and effort, for making the research a great experience.

My family has given me exceptional and constant encouragement, and I thank them all for the support that made things easier to deal with. Thanks to my extended family: Rex, Val, Mark, Sam, and little Jevan. Special thanks to my mum, Susan, for all your years of love, support and guidance, and providing me with everything I needed to get this far in the first place!

And finally, to my wonderful wife Rosemary, who has been there with me through it all and survived! Thank you for unending support, encouragement, inspiration, much needed motivation through good and hard times – but mostly for your love, for being a special partner and friend, and making it all worthwhile.

ABSTRACT

The present study attempted to replicate and extend understandings of differences in the metacognitive experiences of solving insight and well-defined problems. Insight often occurs with a sudden 'Aha!' reaction compared to the more continuous progress typical for well-defined problems. Thirty-two adults completed a within-subjects computer-based problem solving task involving sets of 8 insight and well-defined problems, while providing predictions, feeling-of-warmth monitoring, and evaluations of performance. A sub-sample completed a Problem Solving Inventory (PSI) to compare global and context-specific beliefs of ability. Predictions overestimated performance in both sets, but more so for insight than for well-defined problems. However, correlations between prediction and performance were not significant for either set. No consistent difference in monitoring was found; incremental patterns dominated insight and well-defined problems equally. Averaged evaluations mirrored the overestimation effects of the predictions, although distributions of confidence accuracy were similar across sets. However, interesting correlations were found between global PSI scores and the specific measures, for both problem types. Methodological differences between the present and earlier studies may account for the lack of problem set effects. Conceptual issues need to be addressed regarding definition of insight and verification of insight experiences, particularly if future research is to reconcile metacognitive and cognitive aspects of problem solving.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

Problems of various kinds permeate most aspects of our everyday activities. Hence, problem solving is a fundamental and pervasive cognitive activity (Mayer, 1992), a necessary component in negotiating our daily lives. Solving these problems requires adequate understanding of what the problem situation entails, what steps must be taken to solve the problem, and knowledge of what strategies one may use to reach the goal of solution, as well as the ability to execute strategies to this end. Achievement of a desired solution often requires that one select the most appropriate and efficient strategies to fulfill the identified requirements, while regulating one's attempts at using these strategies in order to keep track of progress towards the goal, and identifying when the solution has been obtained. Furthermore, one's beliefs about problems and problem solving generally, together with both broad and context-specific beliefs about one's own competencies and abilities, may influence the course of one's solution efforts.

Metacognition may be one system through which personal beliefs and selective strategy application have a bearing on the accuracy of problem solving performance. Metacognition refers to a person's thinking about his or her thinking, through the higher-order processes of monitoring, regulating, and evaluating of ongoing cognitive processes (Flavell, 1978). As with other aspects of thinking, metacognition is considered to be a crucial influence in the efficiency and accuracy of people's problem solving activity. Theory and research in this area provide indications that problem solving processes are indeed facilitated by adequate metacognitive skills. While people differ in terms of the complexity and spontaneity of their metacognitive thinking, it appears that these skills can be enhanced through development and training (Hanley, 1995; Hayes, 1980; Simon, 1980). Therefore, metacognitive aspects of problem solving have both psychological and educational implications. The concept of metacognition is both meaningful and fruitful for our understanding of and attention to problem solving abilities.

The present study examines the relationships of metacognitive beliefs and experiences with the performance of problem solving activities. Both 'on-line' and 'off-line' assessments are used to assess the metacognitive knowledge and experiences that participants have in relation to solving problems. On-line beliefs are measured in the form of predictions prior to solution attempts, monitoring during the solution process, and evaluations following completions of a problem set. Off-line beliefs are measured with the use of a Problem Solving Inventory (PSI) that assesses an individual's perceptions of his or her own general problem solving behaviours and attitudes. Furthermore, both on- and off-line beliefs are examined in relation to two general types of problems: well-defined and insight problems. Well-defined problems are typically solved in an incremental, step-by-step fashion towards a given goal. Insight problems typically encourage an obvious but incorrect method that leads to an impasse, which may be overcome by a sudden 'flash' of insight that quickly leads to the correct answer.

The following review examines the relevant literature in problem solving, particularly in relation to insight problems, and in metacognition, with attention on metacognitive beliefs and experiences in problem solving. Problem solving is discussed in terms of the commonly researched well-defined, ill-defined and insight problem structures. Insight is defined and discussed in the context of a classic problem solving model that relates the stages of preparation, impasse and incubation, illumination, and verification. Metacognition is discussed in terms of distinctions between knowledge, executive and procedural control, and affective experiences. These components are considered important to information processing models of problem solving through the metacognitive processes of identification, representation, planning, monitoring, and evaluating. Metacognitive representation and monitoring may be particularly important for solving insight problems; however, while research has demonstrated the positive effects of metacognition on well-defined problems, insight research has proven more complicated and controversial. Measures of subjective metacognitive experiences may increase our understandings of insight processes, although doubts remain as to whether insight involves rapid restructuring of knowledge, and whether unconscious or conscious processes are important in relation to metacognitive appraisals. These issues are debated, before an overview of the present study is presented.

INTRODUCTION

PROBLEM SOLVING

One needs only to consider briefly his or her daily life to realize the pervasive occurrence of problems across time and situation. Problems, differing in nature and severity, abound in whatever domains or contexts within which humans exist: for example, education, research, work place, home, leisure activities, and social relationships. In more demanding cases, problems may tax our abilities to handle the cognitive, emotional, and social demands required in our response to a situation, necessitating reliance on coping activities (Cassidy, 1999; Lazarus & Folkman, 1987). In all cases, the existence of a problem requires adaptation to some situation by negotiating obstacles or barriers that block our progress towards some goal; in short, problem solving.

Problems are distinguished from tasks; "mental demands for which the solution methods are known" (Doerner, 1979, cited in Jausovec, 1994) and that are executed solely from memory recall. Whether a given situation represents a task or a problem depends on the capacities and experience of the person in the situation. Most broadly, a problem exists for a person when "he wants something and does not know immediately what series of actions he can perform to get it" (Newell & Simon, 1972: p 72). Problem solving, then, involves goal-directed thinking aimed at overcoming the obstacles that hinder a person's obtaining of some goal (Davidson & Sternberg, 1998). It is closely related to other cognitive activities, such as perception, attention, language comprehension, memory, decision-making, creative thinking and critical thinking (Swartz & Perkins, 1990). Together, these processes help us to engage and negotiate the situations and duties of daily life.

Conceptualisations of problems and problem solving are numerous (Jausovec, 1994). Newell and Simon's (1972) 'problem space' model is perhaps the most formally explicit and generally applicable model of problems and their requisite solution processes. In this model, developed from an information-processing perspective, problem solution involves the interaction of a problem solver with a specific task environment. Solving processes are activated by the identification and representation of a problem, followed by the selection and application of solution strategies. A person's representation is an internal 'mental model' of the external situation (Davidson, Deuser, & Sternberg, 1994). Problems are represented in terms of some 'problem space', incorporating an initial problem state, a desired goal state, operators or methods, and path constraints. The problem state is the point where problem solving begins, where one realises what problem exists and his or her desire to solve it. The goal state represents the endpoint or solution to be reached. Operators are the methods used to change the initial state and reach the goal state; path constraints include any rules or conditions that limit the operations used. The size of the problem space is determined by the amount of information covered in the representation, and hence the number of operations that can be applied towards an endpoint. Not all solutions may be considered desirable goals, however; search through a problem space may lead to an incorrect solution. Effective problem solution requires the application of operators that allow search through the problem space such that the size of the space is effectively reduced, until only the path to the desired goal remains. A desired solution usually requires either modification of the existing representation, or development of a new representation altogether. Central to the solving of problems, then, are the representations constructed of the situation and the strategies or operations applied to those representations.

1. Well-defined and Ill-defined Problems

Newell and Simon's (1972) conception of problem space is particularly suited to problems that are well-structured. It may be less useful for other types of problem. The most common typology of problem structure distinguishes between well-defined and ill-defined problems (Gilhooley, 1988; Kitchener, 1983; Robertson, 1999). A well-defined problem exists if the elements of problem state, goal state, operators, and path constraints are clearly specified; for example, the problems in Appendix B are considered to be well-defined in nature. An ill-defined problem exists if any or all of these problem elements are vague or unspecified. For example, composing a poem, choosing a career or a marriage partner, finding means to limit pollution are common ill-defined problems; a specific goal may not be defined, one of several feasible solutions may need to be chosen, or the path to a solution may not be easily specifiable. No doubt both problem types exist on a continuum, rather than as a strict dichotomy, of structural definition (Greeno, 1978). Nevertheless, while most research has focused on well-structured problem solving, it is widely acknowledged that most problems of daily life are ill structured in nature (Kahney, 1993; Kitchener, 1983; Kitchener & King, 1990).

The broad distinction between well- and ill-defined problems is not the only, nor indeed the most precise, taxonomy of problem types (see Jausovec, 1994 for a thorough review). Well-defined problems differ amongst each other in important respects, as do ill-defined problems. Therefore, a problem's characterisation may differ depending on the taxonomy that is used to classify it. Nevertheless, the well-defined versus ill-defined division emphasises a significant distinction in the classification of problems that is still considered a useful and meaningful distinction (Ashman & Conway, 1997; Matlin, 1998; Mayer, 1999; Robertson, 1999; Schraw, Dunkle & Bendixen, 1995).

2. Insight Problem Solving

'Insight' refers to the sudden realization of a problem solution, often with a sudden change in one's understanding of the problem, and often with a 'flash' or a sense of surprise that prompts an 'Aha!' response (Davidson, 1995; Dominowski & Dallob, 1995; Metcalfe, 1986a, 1986b). The concept of insight has gained notoriety thanks to anecdotal evidence from biographies of historical figures who reputedly made astounding scientific discoveries or artistic creations through sudden insightful experiences; for example, Archimedes, Newton, and Darwin (Weisberg, 1986, 1993, 1995a, 1999). Insight is a particularly interesting form of problem solving to study given its purported links with creativity, its alleged role in many great discoveries, and because most people have experienced a 'flash' of insight at some point (Sternberg & Davidson, 1999). Also, the concept has historically been shrouded in a degree of mystery and controversy, given the numerous but difficult-to-verify explanations for its occurrence, often citing unconscious processes.

Systematic research into insight processes began with Gestalt psychologists who related the experience of insight in problem solving to perceptual processes involved in observing 'bistable' figures (for example, the Necker cube, the Janov duck-rabbit). These figures can be perceived in either of two forms, and perception of the figures often involves a sudden switch from one form to the other, with no apparent stable transition between the two forms. Gestalt theorists attributed this phenomenon to the holistic reorganization of the parts making up the figure, bringing meaningful order to the whole perceptual structure. In a similar fashion, insight in problem solving is achieved by 'seeing' a problem in a new way, or perceiving some coherent underlying structure (Mayer, 1999). Gestalt psychologists identified two broad types of problem solving: reproductive and productive (Kohler, 1969, cited in Dominowski, 1995). Reproductive thinking involves making use of previous experience, previously acquired knowledge or procedures in order to solve a current problem. The challenge is to identify the right knowledge or procedure to draw on. In contrast, productive thinking requires that one go beyond available knowledge, such that new procedures or knowledge be generated in order to achieve a solution. As Dominowski (1995) notes:

> "Kohler argued that all problem solving concerns awareness of relations and that productive problem solving involves awareness of new relations among problem components. Understanding of these new relations, according to Kohler, is what is meant by insight" (p74).

Insightful productions are marked both by novelty, producing some idea or product that was not previously generated, and by functionality or value, with the new product fulfilling some purpose. Thus, insight processes are related to the wider domain of creativity and creative thinking, also providing a link between puzzle-based problems commonly studied in laboratory research and case studies of creative achievements with greater historical import. Insights may be novel and creative either historically, such as a new scientific discovery or invention that revolutionises how people interact the world, or personally, as when someone solves a puzzle they've never seen before; in the latter case, while a solution may be new for an individual, many other people may have independently produced that same solution in the past (Robertson, 1999).

Classic Gestalt-based studies, while often lacking methodological rigour, often not satisfactorily replicated, and provoking vague explanations for insight, did introduce some intriguing concepts that have inspired modern perspectives on insight and creativity. These studies have paved the way for more rigorous research, extending our understanding of the processes involved.

The problems used to study insight in psychological research are generally defined by three criteria: they can be solved with little specialized knowledge, they commonly lead to an impasse in solution progress, and solution is attained suddenly with some new reorganization of knowledge accompanied by an 'Aha' experience (Dominowski, 1995; Schooler, Ohlsson, & Brooks, 1993). Typically, insight problems differ from ill-defined problems in that the former have specifiable problem states and goal states whereas the latter often do not. However, insight problems often do not have readily identified operations with which to reach a solution, in contrast to more well-defined problems. The key to solving many insight problems is in constructing an appropriate representation, rendering the solution obvious. The difficulty lies in the fact that presentation of the problem usually encourages an inappropriate representation, hence impeding solution.

The occurrence of insight has been set into a wider context of problem solving processes. Gestalt theories, particularly Wallas' (1926; cited in Robertson, 1999; Smith, 1995) classic model, propose four elements of insightful problem solving: preparation, impasse or incubation, insight or illumination, and verification. This model has enjoyed a modern resurgence in popularity, although specific aspects have been criticized. While most theorists generally accept that preparation and verification are elements of all problem solving, the concepts of impasse, incubation and illumination have been subject to some controversy. These latter concepts are assumed to be the defining processes in solution of insight-like problems.

a. Impasse in insight

Solutions to insight problems are often characterized by a preceding impasse, or a period when the solver has no idea or direction of how to proceed. Typically, this is attributed either to the prior generation of an inappropriate representation of the problem or to an inability to generate potential strategies. The solver may realise that existing representations or strategies are not working, but be unable to produce any other useful ideas (Weisberg & Alba, 1981). Gestalt psychologists have demonstrated two factors that appear to promote impasses: mental set and functional fixedness. Stereotypy, or "mental set" fixation, refers to getting 'stuck in a rut', or the tendency to repeat previous strategies that have already proven to be unhelpful; however, one cannot escape the constraining influence of this set in order to try a more useful solution path (Davidson et al, 1994). Functional fixedness refers to the tendency to perceive and relate to an object only in terms of its usual function, even though using that same object for a different function can fulfil the requirements needed to solve a problem (Maier, 1931, cited in Ellen, 1982). In both cases, the inability to break away from inappropriate assumptions based on past experience can lead to impasses in solution attempts.

Two problem space conceptualisations, with differing implications for subsequent solution processes, have been proposed to explain impasses. First, impasses are viewed as searching through the wrong problem space or representation; solution thus requires generating a new, more appropriate representation, through some form of restructuring (Knoblich, Ohlsson, Haider, & Rhenius, 1999; Knoblich, Ohlsson, & Raney, 2001; Schooler & Melcher, 1995). Similarly, lateral thinking has also been construed as the ability to switch from one representation to another, rather than continuing to mine the depths of an unproductive approach: "Vertical thinking is digging the same hole deeper; lateral thinking is trying again elsewhere" (de Bono, 1967: p22). New representations may be generated, and impasses overcome, through several empirically supported processes including relaxation of constraints (inappropriate assumptions) and decomposition of perceptual chunks (Knoblich, et al., 1999), or selective encoding, selective comparison, and selective combination of problem elements (Davidson, 1995; Davidson & Sternberg, 1984; Davidson et al, 1994).

Alternatively, impasses may result from employing the appropriate representation but not generating the correct strategy needed to navigate through the problem space in order to obtain the correct solution; for example, the search space may be sufficiently large that the correct path is difficult to find (Weisberg & Alba, 1981). However, the key to finding the correct path is to employ cued memory retrieval processes based on past attempts; practice and prior experience are helpful, insightful restructuring of existing knowledge is not necessary or helpful. This approach does not preclude a sudden solution; rather, even a sudden solution can occur without restructuring of the original representation. While the "insight" and "incremental" views may both be viable under different circumstances or problems, proponents of the incremental memory-search view tend to discredit the former, insight position.

b. Incubation in insight

Interestingly, researchers have demonstrated that people apparently overcome impasses and produce correct solutions following a period of incubation, or time taken away from mental work targeted on the problem (Mayer, 1995, 1999; Simon, 1966, cited in Robertson, 1999; Smith, 1995). This seems to contradict common sense; that is, *not* thinking about a problem seems to help a person solve it. The correct answer may appear as an insight either during this period of incubation or shortly after one resumes conscious solution attempts. Again, several explanations have been proposed, many focusing on unconscious mechanisms while others disavow any unconscious involvement. For example, Wallas (cited in Weisberg, 1993) implicated the unconscious recombination of old ideas to form new and more productive ideas; recent research provides some evidence for similar processes in terms of non-conscious spreading activation (Bowers, Farvolden, & Mermigis, 1995; Bowers, Regehr, Balthazard, & Parker, 1990; Ohlsson, 1992) and conscious selective combination (Davidson, 1995; Davidson et al, 1994). Breaks from a problem may allow for the substantial decay of an over-activated but inaccurate representation (cf. mental sets) utilised prior to the break, such that returning to the problem allows one to overcome the fixation and develop a new representation that leads to solution (Simon, 1966, cited in Robertson, 1999; Smith, 1995). Alternatively, terms or features in the problem presentation may implicitly cue non-conscious concepts in long-term memory related to the correct solution, priming a person to encode relevant information when it is experienced; related cues from the environment, even if attended to without awareness, may strengthen activation of the primed concepts in long-term memory to a degree that the appropriate concepts for solution suddenly appear in consciousness (Patalano & Siefert, 1994; Siefert, Meyer, Davidson, Patalano, & Yaniv, 1995; Yaniv & Meyer, 1987).

In contrast, Weisberg (1986, 1993) argues that many problems solved following an impasse are not accompanied by the sudden insight implied by the classic interpretation of incubation. He questions whether, given a solution that is generated without suddenness, incubation in the classical sense can be said to occur even if a break in progress is undertaken. Weisberg also suggests that in many cases of supposedly unconscious incubation people actually engage in sporadic, if brief, episodes of conscious "creative worrying" while concentrating on intervening activities. Subsequent progress towards a solution would likely be the result of these brief periods, even if the periods themselves were forgotten; if so, unconscious processes do not need to be implicated.

As with the experience of impasse, the precise processes occurring during periods of incubation may differ depending on the nature of the problems studied, the methods with which they are studied, and the context within which they are studied. Any or all of the above interpretations of incubation, or lack thereof, may be accurate under particular conditions; the task for researchers would then be to systematically determine under what conditions any particular set of processes are invoked. Until further research is conducted towards these ends, it would seem premature to dismiss out of hand any interpretation based on only selected readings of the literature.

Clearly, impasse, incubation and insight are disputed concepts. As with well-defined and ill-defined problems, insight-type problems come in many forms, and can be distinguished in important respects (Weisberg, 1995b). Perhaps this is one reason why studies using insight-like problems have not yielded completely complementary results, and why our understanding of the processes involved in insightful solutions are incomplete. A greater appreciation of the processes and strategies, both cognitive and metacognitive, involved in the solution of insight and well-defined problems may refine our knowledge of the complexity of solution processes involved in these problems and in creativity more generally.

People obviously differ, individually and developmentally, in their abilities to solve problems (Brown, 1987; Jausovec, 1994; Kitchener, 1983; Short & Weissberg-Benchell, 1989); thus research is targeted towards delineating the factors that may help people to improve their problem solving performance. Metacognitive processing may be one set of factors that provides an avenue for understanding and developing such abilities.

METACOGNITION IN PROBLEM SOLVING

The systematic study of metacognition is relatively recent (Bruning, Schraw & Ronning, 1999), although the philosophical roots of the concept date back much further (Yussen, 1985). Interest in metacognition within psychology harks back to the use of introspection by the early structuralist psychologists, in attempting to understand how a person's conscious awareness of his or her thinking affects those very thinking processes (Nelson & Narens, 1990). Contemporary interest arose as a reaction against the negative attitudes of the behaviourist and early information-processing schools towards consciousness (Tulving, 1994). Studying metacognition provides a first-person perspective of knowledge awareness, in contrast to the third-person perspective provided by earlier orientations. Flavell (1971, 1976) is credited with establishing metacognition as a research topic in its own right. He considered this to be "the central problem in learning and development" (1976: p231). Early literature indicates a primary concern with developmental aspects of self-reflective abilities in childhood (Metcalfe & Shimamura, 1994; Yussen, 1985). Also, research focussed largely on memory, as opposed to other cognitive activities.

Flavell (1976) did briefly consider metacognitive aspects of problem solving. He suggested that children's problem solving is enhanced through the planful storage of information considered to be useful for future problem solving, the planful maintenance and revising of information for future retrieval, and the planful retrieval and systematic searching for relevant information when a problem requires solving. Flavell (1976) indicated that children must learn the 'how' (strategies), the 'where' (internal and external information sources), and the 'when' of problem-relevant information usage. He believed that people could become better problem solvers through learning how to improve their abilities to "assemble effective problem solving procedures from already available cognitive components" (p233).

It is apparent in the early literature that little theoretical construction or empirical research had been conducted to develop such ideas. Such theory and research has subsequently been developed, and important findings have appeared (Bruning et al, 1999). Indeed, the concept has proven of interest and worth in many research domains including memory (Bunnell, Baken, & Richards-Ward, 1999; Koriat, 1994, 1998; Leonesio & Nelson, 1990), problem solving (Berardi-Coletta, Dominowski, Buyer, & Rellinger, 1995; Betsinger, Cross, & DeFiore, 1994; Davidson et al, 1994; Davidson, 1995; Jausovec, 1994; Metcalfe, 1986a, 1986b; Metcalfe & Wiebe, 1987), perceptual processes (Bowers et al 1990; Carroll, 1993), language comprehension and production (Brown, Armbruster, & Baker, 1986; Greeno & Riley, 1987; Hacker, 1998; Pereira-Laird, 1996), social cognition (Gollwitzer & Schaal, 1998; Lories, Dardenne & Yzerbyt, 1998; Mischel, 1998), development (Butterfield, Nelson & Peck, 1988; Hertzog & Dixon, 1994; Kuhn, Garcia-Mila, Zohar, & Andersen, 1995; Schneider, 1998), neuropsychology (Shimamura, 1994; Shimamura & Squire, 1986), and motor activity (Simon & Bjork, 2001). Practical fields including education (Mayer, 1998), clinical practice (Dixon, Heppner, Burnett, Anderson, & Wood, 1993; Flett & Johnston, 1992; Mayo & Tanaka-Matsumi, 1996), and business/organizational practice (Smith, 1998; Williams & Yang, 1999) have also incorporated metacognitive perspectives.

At the most general level, Nelson and Narens (1990) provide a broad model for metacognition. They posit the existence of two levels of cognition: a lower 'object-level' at which cognitive activity takes place, and a higher 'meta-level' which contains a dynamic model of, and controls the activity of, the object-level. Two reciprocal types of information flow represent the relationship between these levels: 'control' from meta-level, which regulates and modifies the activity of the object-level; and 'monitoring' from the object-level, which informs the higher level of its activity, and modifies the meta-level model of the lower-level. Primarily, Nelson and Narens (1990) have applied this framework to memory processes, from acquisition to retrieval. However, this model may also be applicable to problem solving, albeit only as a descriptive tool.

Such definitions of 'metacognition' are criticized for their vagueness (Brown 1987; Paris and Winograd, 1990; Jausovec, 1994, 1999). For example, Brown (1987) argues that while the blanket term 'metacognition' encompasses an essential concept, it is rather nebulous and glosses over important distinctions. That is, metacognition is not one underlying process, but rather a set of processes that may differ across task and problem domain. Also, it is often difficult to distinguish 'cognitive' from 'metacognitive' processes (Weinert, 1987). The nature of metacognition also provides measurement difficulties (Paris & Winograd, 1990). Brown (1987) therefore advocates that, in the interests of "clarity and communicative efficiency" (p106), researchers should focus on the specific processes encompassed by the term, and the specific cognitive domains in which it is used (memory, communication, etc.). The term is still of value, however, as an orientation towards thinking of cognitive awareness and development, performance differences, and instruction (Paris & Winograd, 1990; Yussen, 1985). It is rendered more useful if efforts are made to delineate the specific processes under consideration, and to study these in detail as distinguishable but related processes.

In delineating more specific processes of metacognition, most theorists have distinguished between two major aspects: metacognitive knowledge or beliefs, and metacognitive strategies or executive processes (Brown, 1978; Brown et al, 1986; Flavell, 1987; Kluwe, 1982, 1987). Metacognitive experiences or feelings have also been identified as important (Flavell, 1987; Metcalfe, 1986a, 1986b; Metcalfe & Wiebe, 1987; Davidson, 1995). In addition, more recent theories have included motivational factors, such as interest in task-engagement, desire to succeed, self-confidence, and performance attributions (see Ashman & Conway, 1997; Mayer, 1998; Short & Weissberg-Benchell, 1989), and epistemological assumptions (Kitchener, 1983; Schraw, Dunkle, & Bendixen, 1995) in a more comprehensive account of metacognitive activity. The following discussion outlines theoretical contributions to understandings of metacognitive knowledge, executive processes, and affective experiences.

1. Metacognitive Knowledge And Executive Control

Most common in early models is the distinction between declarative and procedural components of metacognition, or between knowledge of cognition and regulation of cognition. For example, Brown (1978) distinguishes between "knowing what", or knowledge of necessary process or strategy, and "knowing how and when" to use an applicable process or strategy. Kluwe (1982) states that the central aspects of metacognition are that a person has knowledge of one's own and others' thinking, and that a person has the ability to control or regulate his or her own thinking. Metacognitive self-appraisal has similarly been conceived as declarative (what you know), procedural (how you think), and conditional (knowing when and why certain knowledge and strategies should be used) (Paris & Winograd, 1990). The declarative-procedural distinction reflects a common differentiation throughout cognitive theory, most notably in theories of memory (Matlin, 1998), but its relevance to problem solving is apparent. Furthermore, acknowledging the metacognitive components of thinking emphasizes the active and self-directive features of cognition.

a. Metacognitive Knowledge

Metacognitive knowledge has been defined as knowledge of cognition (Brown, 1978), "one's knowledge concerning one's own cognitive processes and products, or anything related to them" (Flavell, 1976: p232), and as "the acquisition of knowledge, the amount of knowledge and the assumptions and opinions about the states and activities of the human mind" (Kluwe, 1987: p31). It is clearly a form of declarative knowledge in the form of self-reflective thinking focused on the nature and on-going activity of cognitive processes. Flavell (1976, 1978, 1987), for example, distinguishes among three central forms of meta-level knowledge of cognitive phenomena: person-based knowledge, task-based knowledge, and strategy-based knowledge. Person-based knowledge includes understanding one's own intra-individual differences in ability across content domains, tasks, and time, understanding inter-individual differences in abilities between people within specific domains and tasks, as well as knowledge of universal factors in thinking common to all people, such as the fallibility of short-term memory or that more difficult tasks require greater effort. Task-based knowledge involves an understanding of how different activities or situations demand different types of strategies, processing, and effort. Strategy-based knowledge involves one's understandings not only of particular cognitive strategies that are applicable across different situations, but also of metacognitive strategies that monitor and control the use of lower-level cognitive strategies. Together with these three forms of knowledge, Flavell (1978) notes that sensitivity to knowing when particular forms of knowledge are necessary is an additional facet of metacognitive knowledge.

Kluwe's (1982) model of declarative knowledge explicates the nature of metacognitive knowledge in greater detail. According to Kluwe, at least six forms of metacognitive knowledge are distinguishable across the three dimensions of *domain specificity* versus *generality*, *cognitive activity* versus *transformation of activity*, and *generality* versus *diagnosticity*. He contrasts one's cognitive-level domain knowledge of specific content areas with metacognitive beliefs and assumptions that may be both *domain-specific*, such as believing that one is good at arithmetic but not so good at creative writing, and *domain-invariant* or constant across context. Domain-specific and domain-invariant forms of metacognitive knowledge incorporate understandings of cognitive *states*, *processes*, and *activities* as well as the *means to transform* those cognitive states and activities. These forms may be further divided into *general knowledge* about the organization of cognitive systems and *diagnostic knowledge* that guides beliefs of own and others' thinking in specific situations. For Kluwe, *general knowledge* represents a wide-based belief system about the nature of thinking processes, while *diagnostic knowledge* is organized in the form of self-schemas that integrate beliefs about one's specific abilities.

b. Executive Control: Monitoring & Regulation

Procedural aspects of metacognition have been recognised in terms of regulation or executive control, referring to the directed monitoring and guidance of ongoing cognitive activity. Kluwe (1982) discusses both cognitive and metacognitive aspects of procedural knowledge. At a cognitive level are *solution processes*, the strategies, processes and operations aimed at providing solutions to problems. At a metacognitive level are *executive processes* that monitor ongoing cognitive activity and regulate the selection, application, and effects of available cognitive strategies. The distinction between monitoring and regulation seems particularly important (Nelson & Narens, 1990). Whereas Nelson and Narens (1990) conceive monitoring as distinct from control, Kluwe's (1982) model subsumes monitoring and regulation together under the rubric of executive control. Monitoring of cognition allows for the gathering of knowledge about immediate thought processes, while regulation allows for efficient application of those processes towards perceived task demands in order to complete some task. Both monitoring and regulation are considered processes that provide executive control of thinking.

Brown (1978) states that essential executive skills in the self-regulation of problem solving include *prediction* of one's own capacity to solve a problem, *awareness of appropriate heuristic strategies* and how these should be applied, *identification* of the problem at hand, *planning* of potential strategies into a usable form, *monitoring* of the strategies as they are used, and ongoing *evaluation* of both the processes and products of problem solving to determine a suitable endpoint of one's efforts. Similarly, Kluwe (1982) distinguishes the *monitoring* activities of identification, prediction, checking, and evaluation, from the *executive regulation* of self-motivation and interest, one's resources and their allocation, the intensity of effort in the form of duration and persistence, and speed of processing.

Both metacognitive knowledge and executive control are assumed to be related, though distinct, forms of metacognition. Kluwe (1987) suggests that declarative knowledge and executive control processes operate together when a person is confronted with a problem solving scenario. For example, one's declarative metacognitive knowledge allows one to recognise a problem situation and to encode relevant information about the problem's elements, to provide informed executive decisions about appropriate strategies and plans that may produce a solution. While it is the knowledge facets that provide problem-relevant information for the solver, it is the executive control and regulation functions that allow solution processes to proceed. However, knowledge and executive processes are logically and empirically distinct. Metacognitive knowledge appears to be reasonably stable, consciously statable, and late-developing, while executive processes may be more automatic, not consciously statable, context-dependent across specific tasks, and not age-dependent (Brown, 1978; Bruning et al, 1999; Pereira-Laird, 1996).

2. Metacognitive Experiences

Metacognitive experiences have been identified as affective counterparts of metacognitive self-appraisal but have received less research attention than the knowledge-based or procedural control components (Flavell, 1987; Gick & Lockhart, 1995; Metcalfe, 1986a, 1986b; Metcalfe & Wiebe, 1987; Yussen, 1985). Such experiences, or feelings, are defined as "relatively spontaneous reactions or reflections that occur on line (during the cognitive process) while the cognitive enterprise is rolling along" (Yussen, 1985: p256). Whereas metacognitive knowledge refers to memory-based conceptions of one's knowledge, and metacognitive control is how people use their knowledge and strategy repertoires, metacognitive experiences represent immediate affective and cognitive responses to ongoing activity; for example, miscomprehending the nature of a problem, realizing that one is frustrated with progress on a problem, or having a sense of surprise at suddenly finding a workable solution.

These on-line feelings can be diagnostic, if interpreted correctly, in that they can direct the problem solver to aspects of their cognitive activity that require greater or lesser attention. There appears to be developmental differences in ability to interpret such experiences, with younger children being less able than older children or adults to respond appropriately to their reflective feelings (Flavell, 1987). Metacognitive experiences may also be similar to ongoing attributions about the causes of ease and difficulty in a problem solving episode (Borkowski, Carr, Rellinger, & Pressley, 1990). Gick and Lockhart (1995) suggest that initial affective responses to a problem can motivate a person's decision to ignore or engage in problem solving.

The self-reflective and diagnostic nature of metacognitive feelings may be particularly useful in the continuous monitoring of cognitive activities, particularly problem solving attempts. For example, feelings of warmth or progress towards a goal should guide the direction of a person's subsequent strategies. Feeling that one is working in the right direction will allow narrowing of potential solution paths down to those deemed most productive; feeling that one is not working in the right direction encourages the solver to try a new solution path (Metcalfe, 1986b; Simon, Newell, & Shaw, 1979). This obviously requires a measure of self-reflection involving explicit, or possibly implicit, appraisal of problem-relevant information. However, the affective experiences associated with problem solving may be negative (frustration at lack of progress, annoyance at not solving the problem earlier) as well a positive (pleasure at finding correct solution) (Gick & Lockhart, 1995). The affective quality of metacognitive appraisal may be most apparent in the solution of insight problems; solution to these problems is often accompanied by a sense of suddenness or surprise, resulting in the reputed 'Aha!' reaction (Metcalfe, 1986b; Metcalfe & Wiebe, 1987; Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995). The resolution and affective response to insight problems is similar to that experienced in 'getting' a joke (Gick & Lockhart, 1995).

Distinctions between elements of metacognition, particularly metacognitive knowledge and executive control, have been central to the confusion surrounding the construct of metacognition, and have lead to doubts about the extent to which declarative knowledge and procedural control can be related. Some researchers (e.g. Kluwe, 1982, 1987; Nelson & Narens, 1990; Pereira-Laird, 1996) obviously see the two forms as interactive components, while others argue that either one or the other form should alone be considered as metacognitive. The prevailing belief is that a full appreciation of metacognition and related behaviour requires consideration of knowledge, executive processes, and affective experiences together.

3. Metacognitive Information Processing In Problem Solving

Information-processing approaches to metacognition have applied metacognitive knowledge and control to various higher-order processes across the course of a problem solving episode. Typical progressive metacognitive processes include identification, representation, planning, monitoring, and evaluation (Brown, 1978; Davidson et al, 1994; Flavell, 1978; Kluwe, 1982, 1987); presumably these processes are universally applicable across many domains of problem solving.

a. Identification and problem finding

Identification of a problem is a critical first step; recognizing that a problem exists, and having a desire to rectify the problem, encourages one to engage in problem solving activities. All problem solving reputedly requires the solver to identify, or encode, the relevant features of the problem, to store this information in working memory and long-term memory, and to relate the incoming information to existing relevant knowledge structures (Flavell, 1978; Newell & Simon, 1972). Identification of a problem requires a certain amount of self-reflection on the features of a situation to determine if a problem actually exists; that is, if there are obstacles to be overcome in achieving a goal. Many potential problematic or improvable situations may go unnoticed if a person cannot identify elements in a situation that can be changed. "Problem finding" has recently been identified as an important skill in post-formal adult thinking, and has been related to creative processes (Dominowski, 1995; Lubart & Sternberg, 1995; Perkins, 1981). People who can view existing situations in novel and creative ways can presumably focus on otherwise unnoticed but improvable conditions, or find better methods of organizing situations to facilitate some new goal (Arlin, 1989; de Bono, 1967).

Problem identification may be just as conceptually complex as subsequent metacognitive phases of problem solving. Sufficient identification of a problem and its features allows for mental representation of the problem, prediction of impending success, and planning of solution strategies.

b. Problem representation and solution prediction

Developing a useful mental representation of a problem's structure is essential to engaging in effective solution processes (Newell and Simon, 1972). Many problems may elicit representations automatically, without conscious control (Schooler & Melcher, 1995). However, metacognitive control over representation construction is possible, and is particularly useful where solution to a problem requires a change in representation (e.g. insight problems).

For example, Davidson and Sternberg's (1984; Davidson, 1995; Davidson et al, 1994; Sternberg & Davidson, 1982) three-process model of selective processing, a sub-theory of the triarchic theory of intelligence, outlines three metacognitive processes that influence the development of problem representations: selective encoding, selective combination, and selective comparison. These processes are arguably applicable to all problems, though Davidson and Sternberg emphasize the relevance to insight problems. Selective encoding involves focusing on that information which is deemed most relevant to a correct solution; if a solution is not possible, representational change may require selective encoding of problem features that were originally non-obvious. Selective combination involves integration of problem relevant information into patterns that facilitate solution; impasses in progress may be overcome by combining features in otherwise non-obvious ways. Selective comparison requires the solver to compare new problem-relevant information with existing knowledge, through analogies and metaphors for example, to develop a workable solution; again, non-obvious connections between new and old knowledge can facilitate changes in representation that facilitate solution. Davidson and Sternberg (1984) note that solving a problem may require any one, or a combination, of these processes. Research needs to consider under what conditions and with what problems each of these processes are valuable.

An understanding of the nature of a problem, acquired once a representation has been developed and one's relevant knowledge and competence has been assessed, allows for predictions of imminent solution progress and anticipation of the likelihood of success. Such predictive judgements, or feelings-of-knowing (FOKs) the answer to some problem, are crucial to the forthcoming course of solving attempts: selecting problems that are considered solvable, indicating how much time, effort, and persistence should be allocated, and selecting appropriate strategies that could lead to solution (Kluwe, 1982; Metcalfe, 1998a; Paris & Winograd, 1990). These predictive functions in turn allow for planning of problem attempts.

Interestingly, research across problem solving and other cognitive activities (e.g. memory) has demonstrated a pervasive 'cognitive optimism' in people's predictive judgements; people generally believe that their performance will be better than it actually is (Metcalfe, 1998a). The relation of prediction to performance depends on how it is assessed. Schwartz and Metcalfe (1994) distinguish between micro-predictive and macro-predictive accuracy. With micro-prediction measurement, in absolute terms people tend to perform better on specific tasks that they are more confident about solving than on tasks they are less confident about; in this sense, people are generally accurate at predictive ranking of tasks in terms of relative difficulty. In contrast, macro-prediction refers to comparing the average predictions with respect to overall performance; on average, people overestimate the probability of imminent success. Over-prediction appears to be due to the nature of the information on which people base their estimates; namely, any relevant knowledge that is activated or accessible from memory, regardless of its accuracy (Koriat, 1994, 1998; Metcalfe, 1998a). That is, the more partial, even if inaccurate, information people can access upon cuing of the problem and its representation the higher their predictions tend to be. Unfortunately, the incomplete or inaccurate information upon which estimates are based does not actually help problem solution; hence failure is often the outcome.

The implication of overestimation is that it does not seem to support efficient problem solving; overestimations of success may lead to less efficient monitoring, prompting people to terminate solution attempts before the correct solution has actually been found.

c. Monitoring and evaluation

Monitoring and evaluation are closely related higher-order activities, and may be difficult to distinguish. Monitoring is obviously a central aspect of metacognitive control in most cognitive activities, but has a particularly relevant role in the progress of solution activities as they occur, as discussed above. Monitoring itself represents one form of evaluation process, that of the ongoing solution process. Efficient on-line monitoring and regulation of solution processes may enable greater performance, through the generation of more accurate or useful solution products (Brown, 1978; Kluwe, 1982, 1987).

However, evaluation of the products themselves is also important. Once a potential or partial solution has been generated, the problem solver needs to evaluate the solution to determine if it indeed meets the requirements of the identified goal; if so, solution efforts may be terminated but, if not, the search for a new solution begins or is terminated because the solver does not wish to persevere with the problem. This latter case indicates why monitoring and evaluation are inseparable, because evaluation is ongoing throughout the solution episode until problem-related activity is terminated. Davies (2000) demonstrated the effectiveness of ongoing evaluation in solving a well-structured problem. Performance on the Tower of Hanoi task was enhanced for participants who were required to provide a verbalized or non-verbalized evaluation for each successive move, relative to participants who provided no evaluations. Additionally, participants providing evaluations were disrupted by undertaking a concurrent task while no-evaluation participants experienced no disruption from this task. This suggested that the act of ongoing progress evaluation enabled participants to develop explicit representations of their solution strategies; these representations were open to disruption by increased working-memory load.

Indeed, all of the metacognitive activities identified above may occur in a non-linear form as the problem solver reflects on their activity; all processes presumably occur in an interactive fashion together, and all are necessary if a goal is to be obtained.

Despite distinctions between knowledge, control, and affective experiences, metacognitive activity is assumed to be central to efficient thinking and performance across the course of problem solving. Indeed, Brown (1978) considers executive functioning to be "the crux of efficient problem solving" (p82). Kluwe (1987) suggests that it may be both intra- and inter-individual variations in executive control of thinking that account, to a reasonable degree, for performance differences and deficits. Research has helped establish the veracity of the hypothesized link between metacognition and cognitive performance, but not without controversy. Metacognitive processing has proven to be a challenging construct to investigate empirically, due to the subjective and higher-order nature of the processes suggested by theory.

Informative empirical findings have accrued through the use of 'think-aloud' verbalization techniques, and subjectively-based phenomenological techniques that reputedly tap into metacognitive experiences.

4. Metacognitive Monitoring And Verbalization

The impetus for verbalization procedures arises from the identified need to access a person's flow of conscious thoughts as they engage in a problem, based on an assumption that a person's immediate thoughts contain higher-level self-reflective 'inner speech' that can be characterized as metacognitive. Presumably, if the researcher can gain access to these higher-level thoughts then he or she can observe what metacognitive processes the problem solver is engaged in during the immediate moment of solution activity; this may also allow one to observe in what ways metacognitive thoughts may regulate concurrent cognitive activity and performance (Dominowski, 1998). Verbalization, or 'think-aloud', procedures require participants to speak whatever thoughts come to mind, presumably in working memory, as they work on a task. Verbalization methods may be retrospective or concurrent; concurrent methods may be either directed or non-directed (Ericsson & Simon, 1993). Retrospective methods require participants to describe their prior thoughts shortly after engaging in an activity; concurrent methods require on-line reporting of thoughts while engaged in a task.

Doubts have been cast over the accuracy of verbal procedures to provide a window into people's metacognitive reasoning (Jausovec, 1994; 1999). Nisbett and Wilson (1977) argue that relatively little of our cognitive processes are available to awareness; that these self-reports are subjective and unverifiable, and thus unreliable; and concurrent verbalization may in fact interfere with the processes deemed to be accessed. Jausovec (1994) adds that people can report their cognitions only sequentially, whereas many processes operate in parallel and at a rate too fast to report; also, the use of different coding protocols across studies encourages inconsistent interpretations of verbal data. Research demonstrates that verbalization can be an inaccurate record of cognitive and can adversely effect processing in some cases (Nisbett & Wilson, 1977; Schooler et al, 1993); however this depends on the type of verbalization instructions employed and the exact nature of what processes are under investigation (Brown, 1987; Ericsson & Simon, 1980, 1993). Admittedly, if people are required to provide on-line verbalizations about otherwise non-reportable information, the act of verbalization may hinder actual processing (Schooler & Engstler-Schooler, 1990; Wilson & Schooler, 1991; Brown, 1987).

Nevertheless, think-aloud procedures are one of the more common methods in metacognitive research. Furthermore, their use is supported both theoretically and empirically. For example, Ericsson and Simon (1980, 1993) contend that concurrent verbalization of working memory contents has a neutral, non-disruptive effect on cognitive processes. Where a person reports information that is not readily accessible in verbal form (e.g. some visual information), processing may be neutral but slowed-down as recoding into verbal form takes place. In either case, several commentators (e.g. Lieberman, 1979; Nelson & Narens, 1990) argue that introspective self-reports can be informative if considered as an imperfect means of self-awareness, and interpreted in this light. Verbalizations do not have to provide complete access to underlying processes to be informative and useful. It is the motivating and influential nature of these introspective reports with respect to cognitive performance that necessitates the need to study such processes. Conscious but incomplete thoughts and verbalizations may be particularly informative of metacognitive thinking.

Berry (1983) and Berardi-Coletta et al (1995) have demonstrated that verbalization provides access to metacognitive processes, and that this metacognition improves problem solving performance. Berardi-Coletta et al. (1995) found similar positive transfer results for process-oriented verbalization groups relative to other groups engaged in both the 'Tower of Hanoi' task and the Katona card problem. Two process-level groups (either focusing on process-level metacognitive (MC) monitoring of solutions or making "If…Then" (IT) statements) performed significantly better than other groups (problem-focused (PF), think-aloud (TA) control, silent control) on both practice and transfer trials, in terms of both the ratio of excess to minimum required moves, and time to solution. The researchers demonstrated that beneficial effects were due not to verbalization per se, but to metacognitive processes evoked by the requirement to explain one's thoughts. As expected, process-oriented statements were more common (60% of total statements) for both process groups, less common (5%) for the TA group, and absent for the PF group. These results demonstrated that the shift in processing to a more process-oriented level did indeed induce participants to engage in more metacognitive reasoning, and this improved their performance. Metacognitive statements were not made spontaneously in either the TA or PF groups. In a subsequent experiment, metacognitive (MC) group members, instructed to think about answers to process-level questions rather than to verbalise, performed better than a control group receiving no additional instructions beyond performing the task. This suggested that it is not overt or covert verbalizing per se, but the metacognitive processing induced in participants, that aided performance, a finding replicated by Davies (2000). The type of thinking encouraged by overt or covert thinking is crucial.

These studies demonstrate the usefulness of both verbalization and process-oriented thinking in problem-solving tasks, although the generality of such effects is not yet established. For example, the effects of verbalization may depend on the nature of the task studied (Dominowski, 1998). The studies cited above used well-defined problems; verbalization may not be so effective with non-incremental problems that require other than well-defined solution methods. Schooler et al (1993) have demonstrated that insight problem solving may be subject to the same verbal overshadowing that has been shown with non-reportable processes such as facial recognition (Schooler & Engstler-Schooler, 1990) and aesthetic judgements of taste (Wilson & Schooler, 1991). Using both retrospective and concurrent verbalization methods Schooler et al. (1993) found that participants who were required to verbalise their thoughts while working on both visual and verbal insight problems solved fewer problems than participants not required to verbalize. This negative effect of verbalization did not occur for noninsight problems. Schooler et al. suggested that solution of the insight problems required processes that were not available for conscious inspection; the need to verbalize one's thoughts increases the salience of the verbalizable aspects of the stimulus, thus overshadowing the non-verbalizable aspects. For many insight problems, it may be the non-reportable aspects that allow solution of the problem; if these aspects are overshadowed by verbalization, solution is impeded. Given that language processes appear to hinder at least some insight problem solving, insight processes may operate independently of language and are distinguishable in this sense from more well-defined problems.

Such findings prompt interesting questions about how, or indeed whether, insight problem solving can be studied at a metacognitive level. Not only do insight processes appear inaccessible through verbalization, but also the act of focusing on verbalizable aspects may actually hinder performance. However, insight-related metacognitive processes may be meaningfully accessible through the investigation of another form of higher-order thinking; namely, metacognitive experiences and feelings.

METACOGNITIVE EXPERIENCE IN INSIGHT

Given that verbalization techniques often have a negative effect on solution of insight-type problems, it is necessary to approach insight-based metacognitions from another perspective. Metacognitive experiences or feelings have been identified as emotional counterparts of metacognitive self-appraisals. Insight is an apt area in which to study metacognitive experience given that insight is often accompanied by strong affective responses (Gick & Lockhart, 1995). Research has found that using metacognitive experience measures is useful for studying insight-