The role of feedback about errors in learning a complex novel task.

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The role of feedback about errors in learning a complex novel task

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Declaration

I hereby declare that this submission is my own work and to the best of my knowledge it contains no material previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any other degree or diploma at UNSW or any other educational institution, except where due acknowledgement is made in the thesis. Any contribution made to the research by others, with whom I have worked at UNSW or elsewhere, is explicitly acknowledged in the thesis.

I also declare that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in the project's design and conception or in style, presentation and linguistic expression is acknowledged.

Dianne Gardner

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Chapter 1: Introduction

Human error can have significant consequences. For instance, a recent systematic classification of 178 fatal accidents and 99 serious accidents across a range of industries found that 94% of the accidents were due 'mainly to human error' (Salminen & Tallberg, 1996). On the flight deck, errors accounts for the majority of aircraft accidents (Green, 1990). Although errors are now recognized as being only part of the causal pathway of an accident rather than the principal or sole causal factor, even those errors that do not result in significant or dramatic outcomes like accidents are also associated with costs in terms of poor performance (Hollnagel, 1997; Reason, 1990a; Reason, 1990b). Errors affect effectiveness, efficiency and work quality, and error correction takes up time, raises workloads and increases mental and physical effort (Arnold & Roe, 1987). For these reasons the traditional approach to errors has been to attempt to eliminate them by careful attention to human operators, the technology they use and the interface between them.

Eliminating errors is problematic: some forms of error are difficult or impossible to eliminate entirely. In addition there is an increasing body of evidence that errors may provide information about weaknesses in organisational systems and the limitations of individuals' knowledge and skills. This information represents a valuable learning opportunity, particularly in the learning of complex novel tasks by individuals. It is becoming clear that allowing learners to make errors can benefit the learning process, providing that the negative motivational consequences of errors are managed appropriately. However the mechanisms by which errors can play a constructive role in learning have yet to be fully identified. The present research aims to examine the processes by which errors influence learning and performance on complex tasks, and assess the claims being made for errors as a general source of learning.

Error feedback, error framing, learning and performance.

The value of errors in the learning process is affected by the nature of the feedback provided about errors, and the ways in which errors are framed. Error feedback and error framing in turn impact upon a range of cognitive and affective processes that underlie learning and performance.

Error feedback. Errors can provide task-relevant information in the form of feedback during the learning process. Information provided in feedback can range from a simple statement that an error has occurred to a detailed description of the error and correct response. The impact of different types of error feedback on the learning process has not yet been fully examined. Feedback may contain information about the learning process or the outcomes of learning; it may be positive or negative in direction, and it may vary in the amount of detailed information provided. One issue of particular interest is how the level of detail of feedback about errors impacts upon learning. Goodman (1998), for example, has shown how the level of feedback can affect learning. The mechanisms by which feedback can impact upon the learning process require further investigation. The role of feedback about errors in learning and performance will be discussed in Chapter 3 of this report.

Error framing. Errors in the learning process may be framed in different ways. One way is to see an error as an impediment to learning; another is to see the error as an opportunity to learn more about a task. The frames or interpretations placed upon errors will impact a number of processes in learning. The default frame for errors for many learners may be a negative one: errors are to be avoided. Research evidence shows that errors may be re-framed positively. The impact of such re-framing, and directions for further research will be presented in Chapter 3 of this report.

Cognitive and self-regulatory processes. The information provided by error feedback will impact upon a number of cognitive processes including attention, information processing and mental model development. Error feedback may also provide learners with self-relevant information which may impact upon self-regulatory and affective processes including self-set goals, self-efficacy, satisfaction and intrinsic motivation. Cognitive and self-regulatory processes will also be affected by the ways in which errors are framed. Cognitive and self-regulatory processes and the impacts upon them of error feedback and error framing will be covered in Chapters 4 and 5, and directions for further investigation will be outlined. Chapter 5 also presents an overview and integrative framework for the key constructs to be addressed in the present research.

The present research

This report presents two empirical investigations into errors in learning and performance. In Study 1 we examined the role of different types of error feedback. Non-error feedback, signal error feedback and diagnostic feedback were hypothesized to have differential effects on learning and performance by means of their impact upon cognitive and self-regulatory processes. The research question for the first study was: “How do different forms of feedback about errors affect learning and performance of a complex novel task?”

Study 2 extended the investigation into error feedback by examining the framing of errors. The impact of error avoidance and error management frames upon the mediating processes and the outcome variables was investigated. The research question for Study 2 was: “To what extent do error management instructions enhance the value of signal error feedback compared to error avoidance instructions?”

These studies will be presented in chapters 6 and 7, and the conclusions and implications discussed in the general Discussion, chapter 8.

Chapter 2: Error: definitions and types

This chapter presents a definition of error and an overview of the types of error that are relevant to the discussion of errors in learning presented later in this thesis. The role of errors in learning is also discussed, as this is one of the key concepts underpinning the research questions for this thesis.

Definition of error

A number of broad features of errors have been identified which combine to provide a useful, generally applicable definition. These features are:

1. Errors only appear in goal-oriented action. Without a goal or intention there is no criterion by which to call an action erroneous (Brodbeck, Zapf, Pruemper & Frese, 1993; Frese & Altmann, 1989; Rasmussen, 1987b; Zapf, Brodbeck, Frese, Peters & Pruemper, 1992).

2. Errors imply that the goal was not attained. Not every non-attainment of the goals is an error, however.

3. An error should have been potentially avoidable. Only when actions have been performed that were avoidable can they be considered erroneous (Frese & Altmann, 1989; Zapf et al., 1992).

A definition which incorporates these points and which will be used in the present research is as follows.

> An error is a situation in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency (Reason, 1990, pg. 9).

Types of error

The possible ways of classifying errors appear nearly endless. At the simplest level, two types of error are outlined: errors in which actions do not go as intended (slips and lapses) and errors in which the action does go as intended but fails to reach a desired consequence (mistakes) (Norman, 1983; Reason, 1990b). However the distinction between mistakes and inefficient behaviors is not easy to maintain: inefficient behaviour can be judged without knowing the goals associated with the task but errors can only be judged by knowing the goals. This makes it problematic in deciding whether a given course of action is in fact an error. For this and other reasons this two-way classification is an oversimplification that is of limited usefulness in the study of error. To overcome its limitations a large number of broader taxonomies has been proposed. In fact, a taxonomy of error taxonomies has been presented (Senders & Moray, 1991). These include:

a. *Phenomenological taxonomies*. These describe errors superficially in terms of the events as they were observed. There have been attempts to differentiate between errors of substitution, omission, repetition and insertion (Senders & Moray, 1991); between predictable and random errors (Shaw & Waryszak, 1987); and between errors of omission, errors of commission, sequence errors, timing errors, errors in the selection of options and errors in performance

(Glendon & McKenna, 1995). Other taxonomies consider the nature of the task undertaken such as errors in design, production, test and operation (Brazendale, 1990), the nature of the operation that failed to occur (Kletz, 1991; Kletz, 1994), and the nature of the mismatch between person, task and system (Zapf et al., 1992). Many other examples exist. The most detailed of these models are those used for the analysis of human reliability, which present fine-grained classifications of error and the probability of each (Kirwan, 1995; Kirwan, Kennedy, Taylor-Adams & Lambert, 1997).

b. *Cognitive mechanisms*. These classify errors according to the stage of human information processing at which they occur. Information processing approaches include those which classify errors as occurring during the input, decision and output stages of information processing (Lourens, 1989; Sanders & McCormick, 1987; Singleton, 1989). Another system is to distinguish errors in intention from those in the carrying out of an action (Backstrom, 1997; Norman, 1983; Reason, 1987b; Ridley, 1990). Slips occur as a failure in some action sequence, when the actions are not carried out as intended. Mistakes are errors in which the actions may run according to plan, but the plan is inadequate to achieve its desired outcome.

c. *Errors as the result of biases or deep-rooted tendencies*. This includes heuristics and biases in decision-making (Tversky & Kahneman, 1974). These heuristics refer to a set of fundamental biases in human perception. These biases operate at a subconscious level and are a source of cognitive efficiency (i.e. they enable coping with the overwhelming cognitive demands of every tasks). Many such cognitive coping devices exist which can give rise to biases; these biases can in turn result in errors.

d. *Behavioural taxonomies*: The skill-rule-knowledge classification is the most widely-recognised of these (Rasmussen, 1987b). This taxonomy is discussed further below.

Different taxonomies meet different purposes. Singleton points out the need to distinguish between classifications of causes, effects and remedies (Singleton, 1972) while Senders identifies each type of taxonomy according to its likely users, whether psychologists, lawyers, scientists, reliability analysts, designers, and so on (Senders & Moray, 1991).

The most useful approaches to error classification are likely to be those which are theory-based and empirically testable, with predictive as well as descriptive value. Two such models, the Generic Error Modeling System (GEMS) (Reason, 1987a; Reason, 1990b) and Action Theory (Frese & Zapf, 1994) are outlined below.

Generic error-modeling system

One example of a theory-based taxonomy is the generic error-modeling system (GEMS) (Reason, 1987a; Reason, 1990b). GEMS is based upon the model of performance developed by Rasmussen (1987a, b). Rasmussen's model identifies three levels of control of behaviour: skill-based, rule-based and knowledge-based. Skill-based behaviour takes place without conscious control as smooth, automated and highly practiced patterns of behaviour. Rule-based behaviour involves the more or less conscious selection of routines from a very large inventory of possible routines built up by experience. Knowledge-based behaviour occurs where people have to cope with situations which are new to them and for which they have no routines. This is a fully conscious process of interaction with the situation to solve a problem (Rasmussen, 1982; Rasmussen, 1987b; Ridley, 1990). The level at which behaviour is controlled depends on familiarity with the environment and with the task. People generally try to delegate control of behaviour to the most routine level; if the routine level is not effective then a change is made to the next level. This provides an efficient use of the limited resources of attention. An outline of the distinctions between different types of error according to the GEMS framework is given in Table 2-1.

Skill-based errors (slips and lapses) tend to arise during routine actions. Errors at this level tend to arise from either inattention or overattention to the task at hand or attention at the wrong point in the task. Rule- and knowledge-based errors arise during problem-solving activities. At the rule-based level, failures can occur due to the misapplication of good rules (perhaps due to failure to recognise a situation in which the rule does not apply), or to the application of bad rules. Knowledge-based failures are more complex and diverse and tend to be due to the limited capacity of working memory and to the misuse or over-use of heuristics and biases in information processing (Tversky & Kahneman, 1974). Knowledge-based errors can take on a wide variety of forms, none of which is necessarily predictable on the basis of the individual's acquired knowledge (Backstrom, 1997).

Table 2 - 1 A summary of the distinctions between the three types of error using GEMS (Reason, 1990)

Dimension	Skill-based errors	Rule-based errors	Knowledge-based errors
Type of activity	Routine actions	Problem-solving activities	
Focus of attention	On something other than the task in hand	Directed at problem-related issues	
Control mode	Mainly by automatic processors (schemata)	(stored rules)	Limited, conscious processes
Predictability of error types	Largely predictable "strong-but-wrong" errors (actions)	(rules)	Variable
Ratio of error to opportunity for error	Though absolute number may be high, these constitute a small proportion of the total number of opportunities for error		Absolute numbers small but opportunity ratio high
Influence of situational factors	Low to moderate; intrinsic factors (frequency of prior use) likely to exert the dominant influence.		Extrinsic factors likely to dominate.
Ease of detection	Detection usually fairly rapid and effective.	Difficult, and often only achieved through external intervention.	
Relationship to change	Knowledge of change not accessed at proper time.	When and how anticipated change will occur unknown.	Changes not prepared for or anticipated.

The validity of the skill-rule-knowledge (SRK) framework has been substantiated in a number of ways. For instance, the ease of error detection has been shown to vary for each of the three levels (Allwood, 1984). Slips or errors at the skill-based level are easier to detect than mistakes, or errors at the rule- or knowledge-based level (Reason, 1990b; Rizzo, Bagnara & Visciola, 1988; Sellen, 1994; Zapf, Maier, Rappensperger & Irmer, 1994). A slip is relatively easily detected as the actions are familiar to the user and a mismatch between action and intended outcome is immediately clear. At the rule- or knowledge-based level, errors are harder to detect as the user must recognize a contradiction between an outcome and an intended goal and actions at these levels are less familiar. Knowledge-based mistakes are the hardest of all to detect as expertise is required for the detection of errors at this level (Allwood, 1984).

The skill-rule-knowledge framework has been found to be useful and valid in the investigation of the link between errors and accidents. A systematic classification of 178 fatal accidents and 99 serious accidents across a range of industries found that most of the errors were skill-based, with rule-based being the next most common then knowledge-based errors (Salminen & Tallberg, 1996). The type of error was also often associated with the type of work: individual worker practices tended to be associated with skill-based errors while management practices were more likely to be associated with knowledge-based errors and general equipment practices with rule-based errors (Feyer, Williamson & Cairns, 1997). The GEMS model and its underlying skills-rules-knowledge framework has shown its value as the basis of several techniques for assessing the probability of technological systems failure due to human error (Kirwan, 1995) and is used in the categorization of errors in aviation (Sarter & Alexander, 2000).

Action theory

Action theory is a European model concerned with goal-oriented behaviors (actions) (Frese & Zapf, 1994). An action proceeds from a goal to a plan, to the execution of the plan, to feedback about the action in relation to the goal. Actions can be chaotic as well as orderly; changes can be made while plans are in progress.

An action is regulated by cognitions; the regulation process can be conscious (‘controlled’) or automatic. The levels of regulation are:

- Heuristic level
- Level of intellectual regulation
- Level of flexible action patterns
- Sensorimotor level

The intellectual level of regulation is equivalent to Rasmussen’s (1982) knowledge based level and includes the analysis of goals and conditions, problem solving and decision making. At this level there is conscious, serial processing and the step-by-step interpretation of feedback. The level of flexible action patterns is similar to Rasmussen’s rule-based level and involves the regulation of behaviour by ready-made action programs available in memory which can be, but are not always, regulated consciously. The lowest level of regulation, the sensorimotor level, matches Rasmussen’s skill-based level. At this level action involves stereotyped, automatic movement sequences organised without conscious attention. Conscious regulation cannot modify action programs at the sensorimotor level; at most it can only stop performance. In addition to these three levels is the knowledge base for regulation which has no equivalent in GEMS. This is the heuristic level in which knowledge of facts and procedures is used to develop goals and plans. In action theory, as in GEMS, actions regulated at higher levels require conscious attention while those regulated at lower levels are relatively automatic, with higher levels used for occasional monitoring (Frese & Zapf, 1994).

Action theory gives rise to the following classifications of error according to the level of regulation (Zapf et al., 1992).

- At the knowledge base for regulation there are knowledge errors, when the person does not know how to do a task.

- At the intellectual level of regulation there are several classes of error. Thought errors arise when goals and plans are inadequately developed or wrong decisions are made in planning; memory errors mean that part of the plan is forgotten and not executed and judgment errors arise from failure to understand or interpret feedback after an action.

- At the level of flexible action patterns, habit errors arise when a correct action is performed in a wrong situation; omission errors result when a well-known subplan is not executed (this is common when the task has been interrupted), and recognition errors mean that a well-known message is not noticed or is confused with another.

- At the sensorimotor level of regulation, errors arise in the actual performance of actions.

The action theory taxonomy integrates the taxonomies of Norman, Rasmussen and Reason, with the additional differentiation between the intellectual level and knowledge base for regulation. Validation of this taxonomy includes evidence that errors at different levels of regulation predominate at different stages in the learning process (Frese & Zapf, 1994). Novices tend to have problems at all levels of regulation and with all steps of the action process but especially at the intellectual and knowledge base levels. Errors at lower levels of regulation become more significant as learning progresses (Frese & Altmann, 1989). Errors at different levels of regulation also have differential effects on variables such as error recovery time, need for external support and expertise (Brodbeck et al., 1993; Zapf et al., 1992). The research therefore indicates that, like GEMS, the action theory model of errors is both valid and useful.

It is clear that the more systematic and integrated models of error types, and the models that appear to have the most predictive validity in an organisational context, are based upon the skills-rules-knowledge framework, elaborated in different ways according to the underlying assumptions made about the regulation of behaviour. The skills-rules-knowledge framework will be taken as the basis for the discussion of errors in this paper, as it forms the foundation of both GEMS and action theory models of error types.

Chapter 3: Error framing, error feedback, learning and performance

This chapter discusses the role of errors in learning of complex tasks, as this is one of the key concepts underpinning the research question for this thesis. One complex task of particular and increasing concern is the learning of software programs. An increasing number of people are required to use computers for work and leisure activities, and software packages themselves are constantly changing (Bannert, 2000). This means that a large proportion of the workforce must constantly learn and re-learn software packages. And yet, to quote one recent paper: “Computer software packages are hard to learn but little is known about how to help new users” (Martin-Michiellot & Mendelsohn, 2000). Feedback, defined as ‘knowledge of results’ (Annett, 1969, pg. 12) and as ‘information regarding some aspects(s) of one’s task performance’ (Kluger & DeNisi, 1996, pg. 255) is widely considered to be important for effective learning (Annett, 1969; Ilgen, Fisher & Taylor, 1979; Ivancevich & McMahon, 1982; Wood, 1997). It is therefore important to establish the relative effectiveness of different forms of feedback and, if possible, to identify mechanisms that may boost their value to novice users and to support self-paced learning (Dutke & Reimer, 2000). In this chapter, and this thesis, the primary focus is on feedback that provides information about errors.

Appropriate feedback about errors is important in learning but many complex tasks, such as the use of software programs, are notorious for the low quality of the feedback provided to learners (Dormann & Frese, 1994; Frese, 1991; Frese, 1995; Frese & Altmann, 1989; Frese et al., 1991). Another factor that affects how errors contribute to the learning process is whether errors are framed negatively, as impediments to learning and performance, or positively, as opportunities for learning. Error feedback and error framing will be discussed in this chapter as well as the need for clarification of the effects of these processes on learning.

Errors in training

Individuals react to situations depending upon how they frame or encode those situations. The impacts of errors on learning are affected by the ways in which learners frame the information about errors. Framing can influence the encoding of information related to the self, people, events and situations, which determine the cognitive and affective processes that follow from errors (Mischel & Shoda, 1995).

The default frame for errors has long been a negative one. Early research into one-trial learning and proactive inhibition provided evidence that prior learning of an incorrect response interferes with subsequent learning (Ehri, Gibbs & Underwood, 1988), leading to the argument that learning should be structured so that errors are prevented. In the behaviorist approach, Skinner argued that learning is best accomplished through positive reinforcement and errors were conceptualized as a form of punishment that did not lead to learning but to suppression of behaviour (Skinner, 1968). Within this framework, errors are liable to be interpreted as evidence of failure and this negative self-evaluation can undermine motivation, attention, self-efficacy and performance especially if they are frequent or the trainee cannot easily discover how to avoid them (Bandura, 1997; Debowski, Wood & Bandura, 2001; Frese & Altmann, 1989; Ivancic & Hesketh, 1995;

Wood, Kakebeeke, Debowski & Frese, 2000). Errors also create frustration and anxiety, especially when they require time and complicated handling to resolve (Brodbeck et al., 1993).

The generally negative framing of errors has led to the design of new approaches to the management of errors in learning such as guided mastery and programmed learning. These approaches aim to provide content, test questions and feedback in such a way that feedback is positive, fast and accurate and errors are either prevented or experienced in a manageable form (Ford & Kraiger, 1995). For example, in training novice users of software, a widely-used approach has been to limit the functionality of the software by blocking certain commands during the learning phase, providing learners with only access to those parts of the system necessary for the task in question. Such 'training-wheels' systems are effective especially when combined with detailed guidance and when both the restricted functionality and guidance are faded out as learning progresses (Carroll & Carrithers, 1984; Carroll & Kay, 1988; Leutner, 2000).

Errorless learning techniques have been shown to produce rapid and effective increases in performance (Duffy & Wishart, 1987) but there are good reasons why errors should be included in the learning process. As errors cannot be eliminated entirely, especially in the context of adult learning where learners must use new skills in work tasks without the support of the training environment, it becomes important that learners come to expect errors and cope with them effectively (Frese, 1995; Frese & Altmann, 1989; Pruemper, Zapf, Brodbeck & Frese, 1992). Errors also provide information as to what learners do not yet know, and when errors are made and flagged as such learners can begin to discriminate between errors and non-errors (Frese & Zapf, 1994; Ivancic & Hesketh, 1995). Errors may provide learners with practice in problem-solving and hypothesis-testing (Baldwin & Ford, 1988; Needham & Begg, 1991; Schmidt & Bjork, 1992) and with opportunities to learn how to handle errors and the negative affective reactions that errors may cause (Frese & van Dyck, 1996; Frese, 1995; Frese & Zapf, 1994).

Error training techniques have been developed which explicitly make errors part of the learning process. Techniques for building errors into software training include, for example:

- asking trainees to make as many different mistakes as they can think of;
- presenting common mistakes and having trainees follow through;
- having trainees follow through mistakes made by other trainees;
- presenting screen messages showing different error states and asking trainees to explain how the error had come about and how to get out of the problem situation;
- describing potential errors and solutions in a manual;
- giving trainees problems to solve that exceeded their level of expertise, without guidance or prescribed solutions (Dormann & Frese, 1994; Frese, 1991; Frese & Altmann, 1989; Greif & Keller, 1990).

The superiority of error training over errorless training, especially for complex tasks, has been demonstrated in a number of studies in which participants were trained to use software packages. In these studies error training approaches were contrasted with a traditional error avoidance approach, in which trainees received written instructions that spelled out each step and commands that were to be used for solving the tasks (Frese et al., 1991). Learners who received error training showed better performance, higher motivation and less frustration than participants trained using error avoidance techniques (Dormann & Frese, 1994; Frese, 1995; Frese et al., 1991).

It is not always clear from existing studies which aspects of error training benefit learning, and recent research has identified potential limitations of error training for some tasks. Error training has proved effective for learning structured tasks such as word processing and statistical software (in which the menus provide a set of defined structures for exploring options) but not for the learning of less structured tasks such as CD-ROM database searching (Debowski et al., 2001). For less structured tasks, error training is less effective than structured guided mastery training (Debowski et al., 2001). Explanations for the different effects of error training on different tasks may lie in the task structure as well as the feedback provided to learners (Heimbeck, Frese & Sonnentag, 2001). Research into the relative merits of error-filled versus error-free training has not focused on the amount or type of information about errors, and the effects of different forms of error feedback is a useful focus for future study (Johnson, Perlow & Pieper, 1993). The importance of feedback in learning and issues relating to feedback about errors will be discussed next.

Feedback and the learning of complex tasks

One reason that software is hard to learn is that the feedback provided to computer users by the programs themselves is often unhelpful. Error feedback is informative when it enables learners to understand the nature of the error, what produced the error, how to reduce negative consequences of the error and how to avoid repeating it (Frese & Altmann, 1989; Wood, 1997). In practice the feedback available from most software does not provide this information (Dormann & Frese, 1994; Frese, 1991; Frese, 1995; Frese & Altmann, 1989; Frese et al., 1991). For example, a widely-used statistical package such as SPSS/PC is considered "poor" in terms of feedback design, with unhelpful error messages that do not appear immediately an error is made, and which provide little help to users who 'get lost' in the system (Dormann & Frese, 1994). The feedback provided by electronic search engines has been characterized as "uninformative, providing novice users with little help in developing good search strategies" (Wood, Debowski & Goodman, 2001). Similar comments have been made about a wide range of other software packages. There is considerable scope for improving the feedback provided by software and other tasks that are used in problem solving.

The conventional view of feedback has been that it is beneficial if not essential to the learning process, and that the benefits are due to motivational and informational functions of feedback (Ilgen, Fisher & Taylor, 1979). Feedback about performance relative to a goal or standard can boost motivation. Feedback which provides information about the corrective actions needed to improve performance can guide the development of effective task-relevant strategies (Ivancevich & McMahon, 1982; Wood, 1997). A meta-analytic review of feedback studies has however identified significant challenges to these assumptions about feedback. With regards to both learning and performance outcomes, studies of feedback interventions have reported inconsistent results. Feedback may enhance outcomes, fail to impact upon outcomes or have a detrimental effect on them (Kluger & DeNisi, 1996; Kluger & DeNisi, 1998).

One explanation for the inconsistent results has been the moderating effects of task complexity on the relationship between feedback interventions and learning and performance. For simple tasks, where an increase in effort is associated with improved performance, feedback is generally associated with enhanced performance. For complex tasks where performance depends on appropriate use of rules and strategies rather than simple increases in effort, the motivational effects of feedback can be counterproductive especially if feedback diverts attention away from the task or interferes with strategy development (Kluger & DeNisi, 1996; Kluger & DeNisi, 1998; Wood & Bailey, 1985; Wood, Bandura & Bailey, 1990; Wood, Mento & Locke, 1987). This would suggest that for complex tasks the informational value of feedback can be undermined by its motivational effects. With regard to our earlier example of software, the menus associated with word-processing and statistical programs provide some structure to the learning task and may make feedback more informative than is the case for unstructured tasks such as CD-ROM search tasks. In attempting to understand the impact of feedback on complex tasks, there has been increasing attention to the relationship of the level and source of feedback to learning and performance (Goodman, 1998). This work requires the identification of a range of different types of feedback and evaluation of their effectiveness.

Types of feedback

A number of distinctions are drawn when describing different types of feedback. The most straightforward distinction is between positive and negative feedback. Other distinctions to be discussed are process and outcome feedback, the different forms of process feedback, and the forms that feedback about errors can take.

Positive and negative feedback

Positive feedback indicates that a certain course of action has achieved or is leading towards an intended goal while negative feedback indicates that the goal has not been achieved or that actions have not resulted in progress toward the goal. Positive feedback tells the individual what is known while negative feedback indicates that something is not yet known. In principle, positive feedback should encourage persistence while negative feedback should encourage correction and renewed attention to the task but this is an oversimplification. Positive feedback, when a task is well-known and routine, may lead to a reduction in motivation through a lack of challenge whereas negative feedback can reduce motivation through frustration and anxiety (Baron, 1988). Potentially negative feedback can however be reframed in a positive way, and this issue will be addressed later in this chapter.

Process and outcome feedback

Another major distinction among types of feedback is between process and outcome feedback. Outcome feedback simply provides knowledge of results. It includes information about the number of correct responses such as the number of test items right or wrong, the number of objects produced or whether an answer is correct or incorrect. It is also called verification feedback or corrective feedback (Mory, 1992). Process feedback provides information about the individual's strategy or approach (Earley, Northcraft, Lee & Lituchy, 1990; Ilgen et al., 1979; Jacoby, Mazursky, Troutman & Kuss, 1984). Also called elaboration, instructional or learning-oriented feedback, process feedback focuses on the behavioural process of performing a task rather than the outcomes of that performance. Process and outcome feedback can include positive or negative information or both.

Process and outcome feedback have different effects on learning and performance. Outcome feedback which compares performance with a standard can be an effective motivator for simple tasks or those which are familiar or highly structured (Bandura & Cervone, 1983; Brehmer, 1980; Earley et al., 1990; Hammond & Boyle, 1971; Locke & Latham, 1990; Schmitt, Coyle & King, 1976; Wood, 1997) but it can be dysfunctional if it cues learners to focus on their competence rather than the task (Johnson et al., 1993). In addition it does not provide guidance on how to improve performance (Locke & Latham, 1990; Wood et al., 1987). For more complex tasks where links between inputs and outcomes are unclear, feedback on outcomes has less information value and alone is quite ineffective in guiding learning or performance (Stajkovic & Luthans, 1998; Wood et al., 2001). Outcome feedback alone may impair performance on complex tasks unless learners ignore it or use it effectively in their inferences about the task (Jacoby et al., 1984; Kluger & DeNisi, 1996).

Learning proceeds more effectively and performance is enhanced when learners are given process feedback, including information about how to do a task correctly and why they are in error than when just given outcome feedback, or information regarding the correctness or otherwise of decisions or actions. When good performance depends on identifying effective rules and plans, feedback that provides information about the effectiveness of the strategies that learners need to develop and test will be most beneficial for performance (Wood & Locke, 1990). Process feedback need not identify the correct strategies for the learners; it is also effective when it alerts learners to which information to use in strategy development (Earley et al., 1990; Earley, Wojnaroski & Prest, 1987; Tuckman & Sexton, 1992; Wood, 1997; Wood & Locke, 1990).

Types of process feedback

In an attempt to identify which components of feedback facilitate learning and performance, Balzer identified three different types of process feedback (Balzer, Doherty & O'Connor, 1989; Balzer, Sulsky, Hammer & Sumner, 1992). These are:

1. *Task information feedback*, which provides information about the task system.

2. *Cognitive information feedback*, which provides information about the cognitive strategies being used for the task, such as the use of rules.

3. *Functional validity information feedback*, which provides information about the link between the task system and the cognitive strategies employed.

Studies have found that task information feedback is the essential component of cognitive feedback for improving performance. Task information feedback, whether alone or in combination with the other two types of cognitive feedback, was associated with better performance than no feedback or outcome feedback alone (Remus, O'Connor & Griggs, 1996). Cognitive information feedback alone did not result in better performance than no feedback at all, and adding cognitive information feedback or functional validity information feedback to task information feedback did not improve performance over task information feedback alone (Balzer et al., 1989; Balzer et al., 1994; Balzer et al., 1992; Earley et al., 1990; Hammond & Boyle, 1971; Johnson et al., 1993; Schmitt et al., 1976).

In order to facilitate learning, task information feedback must match task requirements and not overload the capabilities of the individual (Ilgen & Moore, 1987; Rutgers, Atkins & Wood, 1999; Wood et al., 2001). Immediate feedback is more effective than delayed feedback for acquisition of motor skills and when feedback is positive, but for learning tasks that require cognitive processing, and when the feedback is negative, delayed feedback may be more effective than immediate feedback (Ilgen et al., 1979; Mory, 1992; Peeck, Van den Bosch & Kreupeling, 1985). However frequent feedback and feedback given immediately following a task may have a greater impact on practice performance than on learning (Salmoni, Schmidt & Walter, 1984). When performance depends on the identification and use of effective strategies, feedback that provides information about strategy quality and appropriateness should enhance performance (Earley et al., 1990). As a result, greater performance improvements are often found in those areas addressed in feedback compared to other aspects of performance (Johnson et al., 1993). However even task-relevant process feedback can prove counterproductive if it provides confusing or overwhelming information. On a complex task, feedback that provides information on multiple aspects of strategy or task process may leave learners unclear where to focus their attention or how to modify their strategies in order to improve (Wood et al., 2001). However feedback that is overly specific may be beneficial for short-term performance but not for learning or performance over longer time frames, perhaps because specific feedback reduces the extent to which learners systematically explore the problem domain and the extent to which they learn different aspects of the problem (Goodman, Wood & Hendrickx, 2003; Goodman & Wood, 2003).

To be effective, feedback must enable learners to focus on aspects of the task that are relevant and can be manipulated (Kluger & DeNisi, 1996; Kluger & DeNisi, 1998). Feedback which diverts finite attentional resources from the task towards meta-task processes such as self-assessment, affect and other self-regulatory responses reduce the attentional resources available for task achievement and so may impair learning and performance (Kluger & DeNisi, 1996; Kluger & DeNisi, 1998). For relatively simple or well-learned tasks, outcome feedback alone may be sufficient to prompt task-focused attention, especially when it provides information about performance relative to previously established goals (Locke & Latham, 1990). For complex or unfamiliar tasks, outcome feedback not only provides insufficient information for strategy development, it may prompt self-evaluative reactions that divert attention from the task. Process feedback that provides task-relevant information may facilitate task focus (Johnson et al., 1993).

Feedback about errors

There are two broad sources of information that an error has occurred. First, individuals monitor their own actions and compare them with plans and expectations. An error is detected when an action does not go as planned. Second, information from the environment may signal that something is not as expected and that an error has occurred (Reason, 1990b). Information may come from the outcomes of the action, constraints in the environment preventing further action, and information from other people who have detected the error (Johnson et al., 1993; Sellen, 1994). Feedback information from different sources may have different impacts upon performance and learning – feedback from the task itself has been found to be more effective in promoting performance and learning than feedback from sources external to the task (Goodman, 1998). Error detection can be through either process or outcome feedback (Glendon & McKenna, 1995; Olsen & Rasmussen, 1989; Rasmussen, 1987a; Senders & Moray, 1991). In practice both process and outcome feedback often occur together and this combination can be highly effective (Earley et al., 1990; Hammond & Boyle, 1971; Jacoby et al., 1984; Johnson et al., 1993; Seifert & Hutchins, 1992; Wood, 1997) but it is clear that the informational and motivational roles of feedback all play some part in the effects of feedback on complex tasks. Many questions remain about which forms of feedback are effective and the level and nature of information about that should be provided, especially where errors are concerned.

There is at present no established typology for the different forms of error feedback. Three broad categories can however be identified from the literature and from an examination of a range of tasks. These categories are: outcome feedback and two forms of process feedback: signal feedback and diagnostic feedback, which differ in the content and specificity of the information provided to recipients. Each will be discussed below.

1. Outcome feedback

At the simplest level there is *outcome* feedback, which provides information about task performance in comparison with a criterion or norm but includes no information about the type, nature or location of errors committed. Feedback about number of correct responses, amount of production and so on are examples of outcome feedback. Less structured software tasks such as electronic searching tend to provide only outcome feedback such as the number of items a given set of search terms has retrieved. In study 1, outcome feedback was included as a comparative condition to provide a baseline for establishing the impacts of error feedback.

2. Process feedback

In contrast to outcome feedback, process feedback provides information that an error has occurred. Process feedback varies in the specificity of the information that it provides about the location and causes of errors and the correct responses to those errors. Word-processing and statistical analysis software uses menu based structures which provide defined options for learners, and feedback which gives information on the relationship of learners' strategies to outcomes.

2a. Signal error (process) feedback

A less specific form of process feedback about errors is that which simply signals when an error is made but does not provide details about the nature of the error or how to correct it. An example is the highlighting of misspelled words by some word processing programs. Another example, this time from SPSS software, is given in table 3-1a. A review of software packages for word-processing, statistical data analysis, databases and electronic searching (Internet and CD-ROM)[1] indicated that, for menu-based software, the most common form of feedback provided is feedback that signals when an error has been made.

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[1] This review was undertaken by the author. Software designed exclusively for computer-aided instruction, and computer games, was excluded.

2b. Diagnostic (process) feedback

A more specific form of process feedback is *diagnostic* feedback. Such feedback indicates that an error has been committed and how it may be corrected. The information given by some statistical analysis software that repeats an uninterpretable command and makes recommendations as to the correct syntax would be an example of this. An example from SPSS software is given in Table 3-1b. (It is worth noting that diagnostic feedback should be appropriate to the user: the feedback in Table 3-1b ii, while diagnostic in nature, is not intended to assist novices!)

Table 3-1: Examples of diagnostic and signal error feedback from SPSS.

a) Signal error feedback

Motiv1	Motiv2	Motiv1+2
35.00	39.00	?
26.00	24.00	?
31.00	29.00	?
32.00	27.00	?
33.00	29.00	?
37.00	33.00	?
34.00	37.00	?

Transformations pending

b) Diagnostic feedback

i. From SPSS.

Text: MAX7

An undefined variable name, or a scratch or system variable was specified in a variable list which accepts only standard variables.

Check spelling and verify the existence of this variable.

This command not executed

ii. From Windows 95

```
WINWORD caused a general protection fault in module USER.EXE at 0008:0000386f.
Registers:
EAX=00028a34 CS=1767 EIP=0000386f EFLGS=00000202
EBX=00000838 SS=346f ESP=00008a28 EBP=00008a52
ECX=00010118 DS=1697 ESI=0002e128 FS=3d1f
EDX=00000000 ES=346f EDI=00000000 GS=0000
Bytes at CS:EIP:
9a 10 00 00 00 0b ff 75 93 81 7e e4 18 01 74 0b
Stack dump:
8a340001 8aa4346f 00320000 01180838 7dbafff6 3637178f 02f5023b 00000133 8a700f40 00000000 8a700000 00013a9c dd240000 e1280002 3d770002 0002e128
```

Outcome feedback provides relatively impoverished levels of information compared to process feedback (Jacoby et al., 1984; Mory, 1992; Spaai, Reitsma & Ellermann, 1987; Wood et al., 1987). Studies of learning and performance on a CD-ROM search task showed that with outcome feedback alone, learners lacked guidance for the development of effective task strategies and persisted in exploring rather than in applying the strategies they had discovered (Debowski, 1997; Debowski et al., 2001). For many complex tasks, outcome feedback alone does not provide sufficient information for effective learning, although it may act as a motivator once a task has been learned.

The relative effectiveness of diagnostic and signal error feedback has not been clearly established. There is some evidence for the superiority of diagnostic feedback for learning and performance (McKendree, 1990; McKendree & Carroll, 1987) but others have reported no superiority for diagnostic feedback over signal error feedback (Farquhar & Regian, 1994; Spaai et al., 1987). If appropriate to learners' level of understanding, diagnostic feedback should assist learners to learn from errors, to build and refine their mental models and to develop effective strategies for problem solution (McKendree & Carroll, 1987; Smith & Ntuen, 1999; Wood et al., 2001). It should also facilitate short-term performance by providing information about correct responses (Debowski et al., 2001). However diagnostic feedback may also finesse cognitive processes that facilitate the development of cognitive schema and other forms of learning. Provision of the 'correct' answer may diminish motivation to explore the system and as exploration and active problem-solving are associated with more effective learning, diagnostic feedback may prove less effective than feedback which encourages an active approach to learning (Deci & Ryan, 1980; Frese, 1995; Frese et al., 1988; Frese & Altmann, 1989). In contrast, signal error feedback may result in lower short-term performance than diagnostic feedback but better long-term outcomes. This will be the case if signal error feedback provides an incentive to explore and to experiment with the task in a way that promotes learning (Carroll & Carrithers, 1984; Dormann & Frese, 1994; Frese et al., 1988; Frese & Altmann, 1989).

At present, little information exists about the effects of different forms of feedback about errors on learning and performance, and to date no studies have manipulated or controlled the content of feedback about errors and examined the intervening processes. Choices about different types of feedback can be made in the design of tasks or in the supplementation of task feedback so it is worthwhile to examine empirically the effects of the different forms of feedback on learning and performance.

Study 1 focused upon the relative impacts of outcome feedback, signal error feedback and diagnostic feedback upon learning and performance. Based on the existing body of research into feedback interventions it was anticipated that the two types of process feedback (signal error and diagnostic) would result in enhanced learning and performance compared to outcome feedback. Diagnostic feedback was expected to facilitate short-term performance by providing more complete information and supporting the development of effective analytic strategies. Signal error feedback was expected to show delayed effects with ultimate performance being equal to or superior to that of diagnostic feedback, due to learners' incentive to explore and learn from the system. The following hypotheses are therefore proposed:

Study 1 Hypotheses:

- In early trials, diagnostic feedback will result in superior learning and performance to signal error feedback and outcome feedback.
- In later trials diagnostic feedback and signal error feedback will produce superior learning and performance to outcome feedback.

These effects were expected to be moderated by the ways in which errors are framed, and mediated by cognitive and self-regulatory processes. These issues, which are the focus of Study 2, will be discussed in turn.

Error framing

Effective learning from errors will often require that learners' frustration and anxiety about errors are addressed explicitly. Several different lines of research promote the management of the potential negative effects of errors through training. One approach reported by Frese and Altmann (1989) required trainees to work together in pairs, presumably to provide a degree of social support in order to reduce frustration. Another, more detailed approach is that generally known as error management which involves the positive reframing of errors. Individuals react to situations depending upon how they frame or encode those situations (Mischel & Shoda, 1995; Mischel & Shoda, 1998). By reframing errors as an opportunity to learn rather than as evidence of failure or lack of ability, error management aims to prompt an encoding of errors as challenges and opportunities rather than as problems (Dormann & Frese, 1994; Frese & van Dyck, 1996; Frese, 1991; Frese, 1995; Frese & Altmann, 1989; Greif & Keller, 1990; Ivancic, 1998; Ivancic & Hesketh, 1995).

Error management re-frames errors by means of instructions or heuristics designed to counter the emotional and frustrating quality of errors and to increase the problem-solving approach to error correction. Examples of heuristics used in research include the following:

> "I have made an error. Great!"
>
> "There is a way to leave the error situation."
>
> "Look at the screen"
>
> "I watch what is on the screen and what is changing" (Frese, 1991).

The first two heuristics are aimed at reducing the emotional impact of errors; the last two are to assist with the focus of attention and processing of information, as novices often shift their attention from the task to themselves when they encounter errors (Frese et al., 1991). The heuristics are presented before the error training and at intervals throughout. The aim is to reframe errors from being an obstacle to learning and performance to being an opportunity. Such reframing also involves redefining learners' goals and expectations of the training process. If the goal in training is not error-free performance but exploration and understanding of the system then errors may be seen as a natural part of the training process and learners should be able to develop a better knowledge of error prone situations in the system, and to learn to anticipate, handle and avoid repeating them (Dormann & Frese, 1994; Frese & van Dyck, 1996; Frese, 1991; Frese, 1995; Frese & Altmann, 1989; Frese &

Zapf, 1994). Error framing has been shown to help build familiarity with the system, encourage trainees to explore, create a perception that errors were natural, and teach strategies for getting out of situations resulting from errors (Dormann & Frese, 1994; Frese, 1995; Frese & Altmann, 1989; Frese et al., 1991; Nordstrom, Wendland & Williams, 1998).

Investigation into error training has attempted to differentiate the effects of errors in training from the role of the error framing heuristics, which were originally included in much error training research. Results showed that on medium and difficult tasks error training with heuristics produced superior outcomes to either error training with no heuristics or error free training. Error training without heuristics did not differ from error free training (Heimbeck et al., 2001). This suggests that the benefits of error training may not come from errors per se but from the positive reframing of errors.

There have been conflicting findings on the effectiveness of error management training. In learning complex unstructured tasks such as CD-ROM search tasks, guided mastery training in which errors were minimized resulted in better learning and performance than exploratory learning with positive error framing (Debowski et al., 2001; Wood et al., 2000). These results indicate that error training with positive error framing may not be useful with certain tasks, and that one of the key issues may be the nature of the feedback provided by the task (Heimbeck et al., 2001). Research to date has not examined the interactions of error framing with feedback about errors. It is anticipated that the positive framing of errors will have most impact when feedback about errors is relatively impoverished, i.e. for outcome and signal error feedback. The more specific content of diagnostic feedback, which provides guidance on the appropriate responses, can reduce the processing demands and related frustrations for complex tasks.

Study 2 will examine the impacts of error framing on learning and performance, and the interactions of error framing and error feedback. The following hypothesis is proposed:

Study 2 Hypothesis

- Error framing will moderate the effects of error feedback, such that signal error feedback will result in higher levels of learning and performance with positive error framing than with negative error framing. Learning and performance of participants receiving diagnostic feedback will not be affected by error framing.

While the research to date supports the value of positive error framing, there is little information on the interactions between error framing and different types of error feedback, and on the impacts of error feedback and error framing on the cognitive and self-regulatory processes that underlie learning and effective performance. These processes will be discussed next.

Chapter 4: Errors in learning: cognitive mediating mechanisms

Learning is considered to be a process of mental model development and refinement (Ford & Kraiger, 1995; Hesketh, Andrews & Chandler, 1989). True learning effects are those that involve the 'relatively permanent acquisition of skills, understanding, and knowledge' (Goodman, 1998, pg. 224). Measures of task performance are likely to reflect learning effects but may also reflect more transient effects such as the immediate effects of practice and feedback, which may disappear over time (Goodman, 1998).

Mental models, also called knowledge structures, cognitive maps or schemata, are high-order cognitive structures (Manktelow & Jones, 1987). Mental models facilitate the encoding and storage of new information and the recall of old knowledge, and expert performance depends on having an appropriate mental model and accessing it at the right time (Ford & Kraiger, 1995; Gick, 1986; Sweller, 1988). Errors, especially those at the rule-based and knowledge-based levels, often arise from the use of an existing but inappropriate mental model (Manktelow & Jones, 1987). Novice users of word-processors may for instance use the mental model of a typewriter, resulting in predictable errors e.g. in the use of the carriage return (Frese & Altmann, 1989).

Fine-tuning of skills requires that mental models be updated as the task environment changes; errors are an indication that a mental model may no longer be suitable (Olsen & Rasmussen, 1989). In such situations errors can be more useful than correct performance as they help learners to identify incorrect assumptions and problems with their mental models and provide an impetus to revise and update the models (Ehri et al., 1988; Frese &

Altmann, 1989; Frese & Zapf, 1994; Hesketh, 1997; Hovland & Weiss, 1953; Ivancic & Hesketh, 1995; Rasmussen, 1987c). Errors may also remind trainees of analogous problems and problem-solving strategies used in the past (Gick & McGarry, 1992; Hesketh, 1997; Ivancic & Hesketh, 1995). Reminders of previous correct performance and failures play a role in cognitive skill development as attempts to solve problems become part of the mental model of those problems (Read & Cesa, 1991; Ross, 1984). Information about common errors can help learners avoid those errors (Marcone & Reigeluth, 1988) even though it is harder to assimilate and learn from negative information (Holyoak & Spellman, 1993; Hovland & Weiss, 1953; Klayman & Ha, 1987; Oakhill & Johnson-Laird, 1985). Once learners know about potential errors, problem areas can be avoided or extra care can be taken. With experience, errors are also more readily recognised and explanations for errors are more readily available, which also helps to prevent errors or to deal with them once they occur (Ehri et al., 1988; Frese et al., 1988; Needham & Begg, 1991).

The impacts of errors, error feedback and error framing on mental model development and learning are mediated by a number of cognitive and affective mechanisms. These mechanisms are discussed in the remainder of this chapter and the next chapter.

Errors, information and attention

Errors can increase attentional load by increasing the need for active problem-solving (Chandler & Sweller, 1991; Sweller, 1988) and by giving rise to anxiety and frustration (Frese & Altmann, 1989; Kanfer & Ackerman, 1989; Mikulincer, 1989). Factors which increase attentional load during learning can slow schema development. A widely-accepted three-stage model of learning postulates that performance develops from slow, effortful, resource-intensive processing through a stage of knowledge compilation to the point at which skills are automated, require very few controlled attentional resources, and performance appears effortless (Anderson, 1982; Fitts & Posner, 1973; Kraiger, Ford & Salas, 1993; Langan-Fox, Waycott & Galna, 1997; Morrison, Lewis & Lemap, 1997). During the initial, controlled stage of learning the demand for attentional resources is greatest (Kanfer & Ackerman, 1989; Langan-Fox et al., 1997) and tasks that make excessive attentional demands may overload the learner's information-processing capabilities and reduce the capacity available for the development of mental models (Chandler & Sweller, 1991; Sweller, 1988).

This has implications for error training (Frese & Altmann, 1989). At the beginning of training, when the demands on cognitive resources are high, the trainee may be overwhelmed with information and the limits of processing capacity may be reached. In these circumstances, error training may be counterproductive. This would suggest that error training is best carried out in the middle of training, after the initial resource-dependent stage, when learners have the cognitive resources available to deal with it. (Frese & Altmann, 1989). However, the mechanisms by which errors facilitate learning under moderate to high levels of cognitive load require further investigation. Two such mechanisms have been widely discussed. The first is the role that errors and error feedback play in prompting information processing, and the second is the impact of errors on exploration and strategy development.

Depth of processing of information

Errors can engage attention, and attentional capture is important for learning (Hesketh, 1997; Holyoak, Koh & Nisbett, 1989; Kamin, 1969). Kamin (1969) asserts that for conditioning to take place, the conditional stimulus must be surprising and/or novel enough to provoke some 'mental work', and classroom studies have shown that if a response in which the learner is confident turns out to be wrong, there is increased attention to the feedback (Kulhavy, 1977; Kulhavy & Stock, 1989).

It has been argued that attentional capture by novel or unexpected information extends the time spent in controlled processing and prevents actions becoming automated prematurely (Frese, 1995; Hesketh, 1997) but empirical evidence for this proposition has been mixed. Errors engage attention but it is not clear that this results in an extension of controlled processing or that an extension of controlled processing relates to improved learning. The argument that conscious, controlled processing enhances learning is based on the assumption that knowledge compilation takes place slowly to allow non-optimal rules and knowledge to be 'weeded out' and to reduce the chances of erroneous procedures becoming automated (Anderson, 1982; Shiffrin & Schneider, 1977). However several authors question this idea of sequential processing that culminates in a set of 'learned' rules. Anderson (1982), for example, asserts that there is an ongoing development of procedural knowledge. Bargh takes issue with the controlled/automatic dichotomy and argues that complex behaviour requires both simultaneously at all points in the performance and learning process (Bargh, 1989).

A better supported proposition is that errors facilitate deeper processing of information. Level of processing theory argues that memory traces are stronger and more stable when the processing of the information is done at deeper levels (Craik & Lockhart, 1972; Frese et al., 1991). Complex problem-solving activities require effort and place a cognitive burden on the learner (Arnold & Roe, 1987; Chandler & Sweller, 1991; Sweller & Chandler, 1991) but trainees' effort in understanding the training material and generating their own representations is essential if they are to master new but similar problems on their own (Gick & McGarry, 1992; Goldman, 1991; Martin, 1986). Errors make a learning task more difficult which can result in increased effort, deeper processing of information and better learning (Arnold & Roe, 1987; Chandler & Sweller, 1991; Craik & Lockhart, 1972; Frese et al., 1991; Gick & McGarry, 1992; Goldman, 1991; Ivancic & Hesketh, 1995; Martin, 1986; Schmidt & Bjork, 1992; Sweller & Chandler, 1991). Depth of processing is therefore likely to be an important mediator of the link between error feedback, learning and performance. Feedback which requires deeper processing, such as signal error feedback, should result in better learning and recall of the task than feedback which requires less processing, such as diagnostic feedback that provides learners with information about a correct response.

Other mediating factors also affect the processing of information, such as the extent to which learners engage in unstructured trial-and-error learning and in systematic analytic hypothesis testing. These will be discussed next.

Exploration and learning strategy

Error training resembles exploratory or discovery-based training in that it provides a relatively unstructured situation in which trainees seek ways of solving problems and developing their knowledge without time constraints (Ivancic, 1998). Exploratory learning can be defined as learning in which the learners themselves choose which additional knowledge they want to acquire by instigating an appropriate interaction which yields some informative result (Schmalhofer, Kuehn, Messamer & Charron, 1990). This form of learning requires trainees to explore the problem domain in a relatively unstructured fashion.

Exploration-based learning or discovery learning has been found to benefit the development of mental models, in that it can provide opportunities for the learner to ask questions and uncover new information, to relate it to previous knowledge and to extract underlying principles (Dormann & Frese, 1994; Kamouri, Kamouri & Smith, 1986).

When an error occurs, exploration to discover the cause and possible solutions for the error may lead the learner to previously unknown parts of the system and to discover new ways of doing things (Dormann & Frese, 1994; Frese, 1995; Frese et al., 1988; Frese & Altmann, 1989; Frese & Zapf, 1994). Ongoing interaction with and exploration of the system should enable the learner to continually develop their skills. This is an important issue in the use of technology, as self-guided or exploratory methods are the approaches that most novice computer users adopt when learning independently to use software (Dutke & Reimer, 2000; Dutke & Schoenpflug, 1987; Rieman, 1996). It has therefore been argued that effective training should teach and support an exploratory approach, so that trainees explore the system and are encouraged to experiment and to make mistakes (Frese & Altmann, 1989). This approach should develop a better knowledge of the system and better ability to use it outside the training context where errors are inevitable.

There are some issues that need to be clarified with regard to the role of exploration in error training. For exploratory learning to be effective, learners need a clear task or goal and sufficient prior knowledge to ask relevant questions or generate informative interactions with the system being learned, and to interpret the outcomes (Schmalhofer et al., 1990). Exploratory learning therefore depends on prior knowledge to a greater extent than does learning by instructions. The effectiveness of exploration may also depend on students' ability, with more able students gaining more from discovery learning and less able students benefiting from more structured approaches (Carlson, Lundy & Schneider, 1992). Exploration is also time-consuming, and exploratory learning may not facilitate learning under time pressure (Davis & Wiedenbeck, 1998)

For exploratory learning to be effective, learners without prior knowledge of the task or problem domain require guidance from instructors, help facilities, manuals or other resources (Beishuizen, 1992; Carlson et al., 1992; Kemp & Smith, 1994). In naturalistic as opposed to controlled settings, learners may use manuals, other users, or system support personnel to assist their self-initiated exploratory learning but most still consider such learning to be inefficient (Rieman, 1996). Computer tutors can provide effective guidance if the tutors only correct errors which learners cannot resolve for themselves (Schmalhofer et al., 1990). Computer tutors that correct every error hinder learning, as learners cannot test their hypotheses and follow their trains of reasoning through (Schmalhofer et al., 1990). Exploratory learning is most effective when trainees have the skills needed to process and learn from information gathered during exploration or where there is support from either an instructor or a tutorial system built in to the system being learned.

The nature of the exploration also needs to be considered. The research evidence does not support advantages of unstructured or trial-and-error exploration in which trainees are left to their own devices without guidance or help. Such approaches may be detrimental to learning if learners cannot get themselves out of error situations or understand what caused an error (Frese & Altmann, 1989). In complex decision tasks where learners must identify the requirements for good performance without systematic instruction, effort may be unproductive if used inefficiently or wasted in uninformative approaches. A good strategy for learning a complex and ill-structured task is for learners to construct hypotheses or tentative rules as to how various factors will affect outcomes and then test those hypotheses (Dormann & Frese, 1994; Frese et al., 1988). When a range of different factors affects performance on a complex task, the relative contributions of different factors can be identified by testing each in turn and observing the effects. A poor strategy is to develop vague or complicated rules or to test several factors together, making it hard to identify the sources of effects with multiple causes (Wood & Bandura, 1989). Unsuccessful attempts may suggest new paths of inquiry but for very complex tasks learners lose track of approaches that have been tried and their levels of success (Debowski et al., 2001). Unstructured trial-and-error exploration is less likely to be associated with effective learning than systematic, strategy-based exploration, and exploration in itself is less important than the quality of learners' analytic strategies (Debowski et al., 2001; Wood & Bandura, 1989; Wood et al., 1990; Wood et al., 2000).

The effects of error feedback on strategy and exploration have not yet been clarified. When feedback is ambiguous and does not help strategy development, trial and error learning is time-consuming and wasteful compared to more structured learning approaches (Debowski et al., 2001) and trainees may never identify effective strategies. Feedback assists performance when it provides information that contributes to task understanding and facilitates the selection and evaluation of task-specific plans (Wood & Locke, 1990). Although the effects of different forms of error feedback on learning and performance have yet to be studied, the effects of error feedback could be expected to be mediated by factors including exploration and quality of analytic strategies, as argued above.

On complex tasks, effective feedback is that which facilitates exploration, hypothesis-testing and strategy development. Outcome feedback provides little information on the effects of rules on outcomes and thus little guidance for improving strategy. Process feedback provides better support for strategic learning approaches. Process feedback need not identify correct strategies: it is also effective when it alerts learners to which information to use in strategy development (Earley et al., 1990; Wood, 1997; Wood & Locke, 1990). Diagnostic feedback provides information for learners to develop and test their hypotheses yet it may also act as a disincentive to exploration by providing clear guidance as to optimal courses of action. Signal error feedback should encourage exploration but provides less guidance on strategy development. Thus exploration should be accompanied by greater depth of processing, which will enhance learning and performance over time. Due to the greater guidance provided by diagnostic feedback, effective strategies should appear early in the learning task and result in higher levels of performance. However diagnostic feedback requires less processing by recipients. In comparison, signal error feedback is likely to be associated with more trial-and-error exploration, slower development of strategy and, while effective in the longer term, high levels of learning and performance may take some time to appear. The following hypotheses are therefore proposed:

Study 1 hypotheses:

- Diagnostic feedback will result in better strategies, less depth of processing, and less unsystematic exploration, than outcome or signal error feedback.

- Strategy, exploration and depth of processing will mediate the relationship between error feedback and learning and performance outcomes.

Study 2 investigates the interactions between error feedback and error framing. The positive framing of errors can prompt trainees to explore (Frese & van Dyck, 1996; Frese & Altmann, 1989), and to use better, hypothesis-driven exploration strategies than negative error framing (Frese, 1995). As signal error feedback is expected to result in slower learning than diagnostic feedback, it is anticipated that error management instructions will be better than error avoidance instructions in facilitating depth of processing and strategy for signal error participants. These differences should not be so apparent for participants receiving diagnostic feedback in which the feedback itself supports processing and strategy development. The following hypotheses are proposed:

Study 2 hypotheses:

- Error framing will moderate the impacts of error feedback such that signal error feedback will result in better strategy, less exploration and more depth of processing with positive error framing than with negative error framing. Strategy, exploration and depth of processing for participants receiving diagnostic feedback will not be affected by error framing.

- Exploration, depth of processing and quality of decision strategies will mediate the relationship between error feedback and error framing, and learning and performance outcomes.

Chapter 5: Errors in learning: Self-regulatory mediators

Feedback is the basis for self-regulatory activities (Bandura, 1977; Bandura, 1986; Bandura, 1991a; Bandura, 1991b; Bandura, 1997; Ilgen et al., 1979; Kanfer, 1992) which influence the cognitive processes that underpin learning and decision making (Wood & Bandura, 1989; Zimmerman, 1995). Self-observation is of limited use without information about progress (Bandura, 1986). Key regulators of intentional behaviour include self-efficacy or self-assessment of ability to perform the task, evaluation of performance against a standard or goal, and affective self-reactions including self-satisfaction. This chapter will discuss these processes in the context of learning from error feedback and error framing.

Self-efficacy

Self-efficacy is the belief that one is capable of performing a task. It does not concern specific skills as much as a person's belief that they can use those skills. It is based upon an analysis of task requirements, experience with such tasks in the past, and personal constraints and resources such as skills, motivation and competing demands and distractions (Bandura, 1986; Bandura, 1989; Gibson, 1996; Gist & Mitchell, 1992; Moriarty, Douglas, Punch & Hattie, 1995; Wood & Bandura, 1989; Wood et al., 1990; Wood & Locke, 1990). Experience with a task, especially experience of success, is an effective way to influence self-efficacy (Cervone, Jiwani & Wood, 1991; Mitchell, Hopper, Daniels, George-Falvy & James, 1994; Wood, 1997; Wood & Locke, 1990).

Performance on complex tasks is strongly influenced by beliefs of personal efficacy (Bandura, 1997; Bandura & Jourden, 1991; Gorrell & Capron, 1989; Schunk & Swartz, 1993; Tabernero & Wood, 1999). Self-efficacy beliefs have been found to be as important as ability for successful performance in both experimental tasks and in the workplace (Bandura, 1986; Bandura, 1997; Bandura, 1998; Sadri & Robertson, 1993; Stajkovic & Luthans, 1998; Tannenbaum & Yukl, 1992).

Perceived efficacy affects problem-solving performance both directly and by its impact upon other self-regulatory factors (Bandura, 1997; Tabernero & Wood, 1999; Wood & Bandura, 1989; Wood et al., 1990; Wood & Locke, 1990). High self-efficacy is associated with higher self-set goals, stronger commitment to those goals, better problem-solving and analytic strategies, more effort and persistence in the face of difficulties and a tendency to interpret poor performance in constructive rather than debilitating ways (Bandura, 1997; Bandura & Wood, 1989; Debowski, 1997; Debowski et al., 2001; Gibson, 1996; Gist & Mitchell, 1992; Kanfer & Kanfer, 1991; Silver, Mitchell & Gist, 1995; Tabernero & Wood, 1999; Wood, 1997; Wood et al., 1990; Wood et al., 2000). Those with high self-efficacy are also more likely to attribute failure to controllable causes and to intensify their efforts, to explore strategies and to engage in other proactive approaches to improving performance (Ho & McMurtrie, 1991; Locke & Latham, 1990; McColskey & Leary, 1985). The relationship between error feedback and self-efficacy is reciprocal (Wood, 1997; Wood et al., 2001). Feedback will influence an individual's assessment of their capabilities (Bandura, 1997) but the reaction to and the instructiveness of error feedback will depend upon the learner's receptiveness to it which is influenced by self-efficacy (Debowski et al., 2001; Nease, Mudgett & Quinones, 1999).

The impacts of different types of error feedback on self-efficacy require clarification. Process feedback such as signal error and diagnostic provides task-relevant information which should enable learners to develop higher self-efficacy for a task than outcome feedback will. Diagnostic feedback, which provides more complete information, should result in higher self-efficacy in learners than signal error or outcome feedback. Positive error framing should assist learners to remain focused on the task and should result in better self-efficacy than error avoidance framing. Self-efficacy is likely to be a key moderator of the impacts of error feedback. A lack of detailed feedback about the task should have a more deleterious impact upon the learning of those with low self-efficacy than those with high self-efficacy, as learners with low task self-efficacy are more likely to respond to impoverished levels of feedback about the task or with less effective learning strategies (Wood et al, 2001).

Goals

Another key process in individual self-regulation is the setting and revision of goals. Goals provide standards against which performance can be evaluated and this comparison affects performance through the amount of effort and attention directed to a task, as well as through persistence, planning and strategy (Earley, Connolly & Ekegren, 1989; Earley & Lituchy, 1991; Earley et al., 1987; Kanfer, 1992; Kanfer & Kanfer, 1991; Locke & Latham, 1990; Locke, Shaw, Saari & Latham, 1981). Self-regulatory processes therefore require both a goal (an internal standard of comparison) and knowledge about performance. A goal provides a criterion that allows an action to be classified as correct or erroneous: many errors cannot be identified as such unless the individual's goals are known. Goals may be set externally or individuals may set their own goals, often in response to feedback (Johnson et al., 1993; Podsakoff & Dalton, 1987).

While the value of goal-setting has been established in a wide range of situations, the effectiveness of goals depends upon a number of factors. Goals that are specific and challenging provide a clearer guide and greater motivation for performance than do easy or vague goals, providing that the individual is committed to the goals and has the means to achieve them (Bandura & Cervone, 1983; Locke & Latham, 1984; Locke & Latham, 1990; Locke et al., 1981). However while specific goals may facilitate performance of a familiar task, they may impair learning of a novel task if they prompt learners to focus on identifying solutions for a specific problem rather than on developing an understanding of the overall structure of a problem space (Vollmeyer, Burns & Holyoak, 1996).

The size of goal effects varies as a function of task complexity (Wood et al, 1987) and for complex tasks the effects of goals are further mediated through plans and strategies. Where successful performance hinges upon effective choice and use of strategy rather than upon increased effort, difficult goals may promote better use of available information and more effective task strategies (Wood & Bandura, 1989) or they may impair performance by increasing attentional load, distracting learners from the task, or encouraging persistence with non-productive strategies (Cervone & Wood, 1994; Earley et al., 1989; Wood et al., 1990; Wood, George-Falvy & Debowski, 2001; Wood & Locke, 1990). Highly specific goals may lead to a search for highly specific plans or strategies which in turn may be counterproductive given high levels of task complexity (Vollmeyer et al., 1996; Wood &

Locke, 1990). Effective goals are those which are appropriate to the individual, the situation and the task.

By providing task-relevant information, process feedback is expected to prompt learners to set themselves higher goals than outcome feedback. Diagnostic feedback, which provides more information, should result in higher goals than signal error feedback or outcome feedback. By mitigating the negative affective responses to error and by prompting increased task focus, positive error framing should prompt learners to set themselves higher goals than negative error framing, especially when feedback about the task is relatively lacking in detail as in signal error feedback.

Intrinsic motivation

There have been conflicting findings on the impacts of feedback about the task and error framing on intrinsic motivation, or the willingness to engage in a task for its enjoyment value (Deci & Ryan, 1980). Exploratory learning and error framing approaches have been found to have positive impacts upon intrinsic motivation compared to error avoidance training (Deci & Ryan, 1980; Frese & Altmann, 1989) but there are conflicting findings in this area, with data indicating that error avoidance training is more positively associated with intrinsic motivation than error training with positive error framing (Debowski et al., 2001). The effects of intrinsic motivation on outcomes are also unclear. The high levels of intrinsic motivation resulting from positive error framing were found to be associated with greater interest and persistence in one study (Dormann & Frese, 1994). However, high levels of intrinsic motivation did not impact upon effort, learning or performance other studies (Debowski, 1997; Wood et al., 2000) and were also associated with poor use of analytic strategies, a consequence of highly motivated participants continuing to use non-systematic and exploratory strategies (Wood et al., 2000).

The relationships between error feedback, error framing and intrinsic motivation have yet to be clarified. Process feedback such as signal error and diagnostic should enable learners to develop and maintain higher levels of intrinsic motivation for the task than outcome feedback. Diagnostic feedback, which provides more complete information, should result in higher motivation than signal error or outcome feedback. Positive error framing, rather than error avoidance framing, should assist learners to maintain motivation for the learning task.

Affective reactions

Self-regulation includes a process of monitoring actions and comparing the outcomes with salient reference points, values or goals, and a second process in which the *rate* of progress towards the desired outcome is monitored. It is this second, meta-function that gives rise to affect (Carver & Scheier, 1990).

According to Carver and Scheier (1990), negative affect arises when an individual's rate of progress towards an internally established standard or reference value falls short of the expected rate. Positive affect arises when progress exceeds the expected rate. When the rate of progress meets the expected standard then affect is neutral. Progress towards desired goals in itself does not determine affect; it is the comparison between the rate of progress and the expected rate of progress that does. Progress can be monitored towards more than one goal concurrently, and at different levels of abstraction. This means that a single event may produce a range of affective reactions if that event is relevant to multiple goals.

As well as providing information about rate of progress, this meta-function allows the rate itself to be managed. When progress is at an acceptable, steady rate and affect is neutral, then progress is maintained. An unacceptably slow rate of progress accompanied by negative affect results in attempts to facilitate progress or to re-evaluate goals and strategies. This mechanism explains why negative affect (dissatisfaction with deficient performance) may initially spur increased effort but in the longer term undermines motivation (Cervone et al., 1991; Wood et al., 2001). When the rate of progress exceeds the expected rate and positive affect results there may be a reduction in subsequent efforts and 'coasting', thus allowing effort and resources to be diverted to other concurrent goals.

The Carver and Scheier (1990) model of affective processes may help to account for some inconsistent findings from research into error training and emphasize the importance of considering and managing affective processes. When errors retard progress below the desired rate they give rise to negative affective reactions (such as self-dissatisfaction). Negative affect in turn prompts a reassessment of the likelihood of attaining the goal. This assessment can result in increased effort or amended strategy or, if the individual's assessment of their likelihood of success is low, disengagement from the goal. If, on the other hand, errors speed progress towards the goal above the expected rate, they will result in positive affective reactions (such as self-satisfaction). This becomes feasible when it is recognised that an error may impede progress at the behavioural level but facilitate progress towards higher-level goals such as learning, understanding or mastery of a task. In this situation, errors may be associated with positive affect.

The effects of rate of progress upon affect will therefore depend upon the goal that the individual is pursuing. For example, if errors retard performance but enhance learning, then reactions could be either negative or positive depending on whether the person is pursuing a learning or performance goal. Non-error outcome feedback provides information on progress in relation to a performance goal and affective reactions will therefore depend on whether the rate of progress is considered by the learner to be satisfactory or not. Process feedback may provide information relevant to higher-level goals (e.g. learning) and impact most upon affect when these goals are salient for the individual. Affective processes are therefore an important mediator of the relationship between type of error feedback, learning and performance.

Goals, reference values and standards are amenable to external manipulation (Carver & Scheier, 1990; Locke & Latham, 1990). Error framing may reframe goals from task performance to learning, in which case errors need not interrupt the rate of progress towards the goal. Errors would therefore lead to neutral affect if rate of learning remains acceptable to the learner, or to positive affect if the error is seen to have facilitated learning above the predetermined rate.

Process feedback such as signal error and diagnostic should provide learners with relevant information about their task performance and so should be associated with more positive affective reactions than outcome feedback. Diagnostic feedback should result in more positive affective reactions than signal error or outcome feedback. Positive error framing, rather than error avoidance framing, should be associated with positive affective reactions towards the learning task.

In summary, there is evidence to support an argument that both the form of error feedback and the framing of errors will impact upon components of the cognitive-affective processing system, but these effects, and the subsequent impacts on learning and performance have not been investigated directly.

In Study 1, where the effects of the different forms of error feedback on self-regulatory processes will be examined, the following hypotheses are advanced:

Study 1 hypotheses:

- Signal error feedback and diagnostic feedback will result in higher self-efficacy, higher goals, higher intrinsic motivation and greater satisfaction than outcome feedback.

- Self-efficacy, self-set goals, intrinsic motivation and affect (satisfaction) will mediate the relationship between error feedback and learning and performance outcomes.

- Self-efficacy will moderate the relationship of feedback type to learning and performance. Individuals with high self-efficacy will show similar learning and performance when provided with signal error feedback, diagnostic feedback or outcome feedback while individuals with low self-efficacy will show poorer learning and performance when receiving outcome feedback than when receiving signal error feedback and diagnostic feedback.

In Study 2, where the interactions of error feedback and error framing on self-regulatory processes will be examined, the following hypotheses are proposed:

Study 2 hypotheses:

- Error framing will moderate the impacts of error feedback such that signal error feedback will result in better self-efficacy, goals and affect with positive error framing than with negative error framing. Self-efficacy, goals and affect for participants receiving diagnostic feedback will not be affected by error framing.

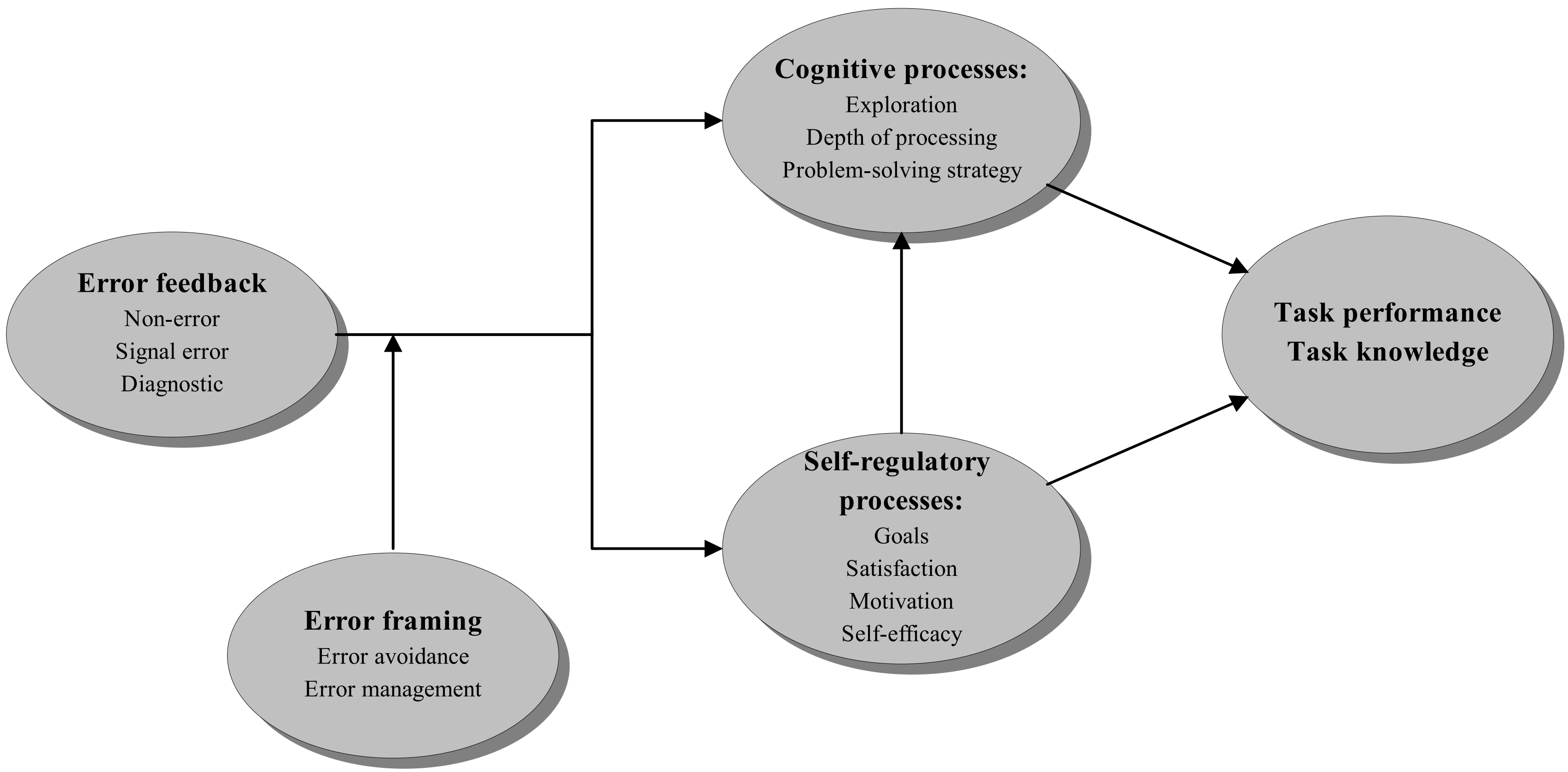
- Self-efficacy, self-set goals and affect (satisfaction) will mediate the relationships between error feedback and error framing, and learning and performance outcomes.

Overview and integrative framework

Figure 5-1 summarizes the processes by which error feedback and error framing impact upon the cognitive and affective processes that influence learning.

Error feedback can range from a simple statement that an error has occurred (signal error feedback) to a detailed description of the error and correct response (diagnostic feedback); alternatively a learner may receive no feedback about their errors. The first study presented in this report focuses upon the relative impacts of outcome feedback, signal error feedback and diagnostic feedback upon learning and performance. It is hypothesized that the two types of process feedback (signal error and diagnostic) will result in enhanced learning and performance compared to outcome feedback. Diagnostic feedback is expected to facilitate short-term performance by providing more complete information and by supporting the development of effective analytic strategies. Signal error feedback is expected to show delayed effects with ultimate performance being equal to or superior to that of diagnostic feedback, due to learners' incentive to explore and learn from the system.

Figure 5-1 Errors and learning: hypothesized moderating and mediational processes



The impacts of error feedback are likely to be affected by the ways in which errors are framed and the second study will examine the interactions of error feedback type and error framing. It is hypothesized that the positive framing of errors will have more impact for outcome and signal error feedback than for diagnostic feedback.

The effects of error feedback and error framing are mediated by cognitive and self-regulatory processes. The cognitive processes examined in the present research are depth of processing, exploration and quality of analytic strategies. Diagnostic feedback is expected to result in better strategies, less depth of processing, and less unsystematic exploration than outcome or signal error feedback. Positive error framing is expected to result in more effective use of cognitive processes than negative error framing, especially when signal error feedback rather than diagnostic feedback is provided.

The self-regulatory processes studied are goals, satisfaction, intrinsic motivation and self-efficacy. Signal error and diagnostic feedback are hypothesized to result in more effective self-regulation than outcome feedback. Provision of positive error framing is hypothesized to enhance the effects of signal error feedback on self-regulation, compared to negative error framing.

The next chapter presents the findings of Study 1.

Chapter 6: Study 1 - The effects of different forms of error feedback

Aim and hypotheses

The aim of Study 1 was to investigate the effects of different types of error feedback in performance and learning of a complex novel task. Three groups of participants, representing three different feedback conditions, worked on a computer-based simulation of a management task. Data on task performance, learning (declarative knowledge), analytic strategy, exploration, depth of processing, self-efficacy, goals, motivation and satisfaction were recorded. Two forms of feedback about errors were investigated: signal error feedback, in which the location and nature of an error were indicated but means to resolve the error were not given, and diagnostic feedback which provided information about errors supplemented with information about correct responses. A third comparison condition provided regular outcome feedback with no specific information on errors or correct responses.

The hypotheses for this study were as follows:

> *Hypothesis 1A*: In the first block of trials, diagnostic feedback will result in superior performance to signal error feedback and outcome feedback.
>
> *Hypothesis 1B*: In the second block of trials diagnostic feedback and signal error feedback will produce superior performance to outcome feedback.

Hypothesis 1C: Diagnostic feedback will result in superior learning compared to signal error and outcome feedback.

Hypothesis 2: Diagnostic feedback will result in better strategies, less depth of processing, and less unsystematic exploration, than signal error or outcome feedback.

Hypothesis 3: Diagnostic feedback will result in higher self-efficacy, higher goals, higher intrinsic motivation and greater satisfaction than signal error or outcome feedback.

Hypothesis 4: Strategy, exploration and depth of processing will mediate the relationship between error feedback and performance and learning outcomes.

Hypothesis 5: Self-efficacy, self-set goals, intrinsic motivation and affect (satisfaction) will mediate the relationship between error feedback and performance and learning outcomes.

Hypothesis 6: The relationship of feedback type to performance and learning will be moderated by participants' level of self-efficacy. Participants with high self-efficacy will show similar performance and learning whether provided with diagnostic, signal error or outcome feedback, while participants with low self-efficacy will show poorer performance and learning when receiving signal error and outcome feedback than when receiving diagnostic feedback.

Method

Participants

Participants were 19 men and 29 women participating in undergraduate classes in Commerce, Economics and Materials Science. Their average age was 19.7 years (SD = 1.69). Participants were randomly allocated to each of three feedback conditions (described below). There were 16 participants in each condition.

The task

The significance of feedback about errors in learning is likely to be greatest on tasks that are both complex and novel. On complex novel tasks, errors are an inevitable part of the learning process as individuals attempt to discover effective decision rules. The task selected to test the experimental hypotheses was both complex and, importantly, one with which all study participants were equally unfamiliar. The task was a simulation of a group management situation that has been widely used in research into learning, performance, cognitive and self-regulatory processes and has proved valuable in studies of this type (Tabernero & Wood, 1999; Wood & Bandura, 1989; Wood & Bailey, 1985; Wood et al., 1990).

The study was presented as a study in management decision making in which participants would manage a simulated organisation. The introductory information described the simulation as one in which they would act as managers of a small factory manufacturing furniture. Participants were responsible for the production of weekly orders and managed the organisation for a total of twelve simulated weekly orders, with each order representing a performance trial in the simulation. The experiment was completed in a single session taking approximately one hour.

Participants' task was to allocate workers from a five-member roster to each of five production jobs in order to complete the work assignment within an optimal period. These jobs were: assembly, fabric cutting, sewing, upholstery and warehousing. Participants could reassign employees if they felt that a particular employee would be better suited for a different job assignment. By correctly matching employees to jobs, participants could attain a higher level of performance than if employees and jobs were poorly matched. To assist in the decision task, participants were given descriptions of the characteristics of each employee and their abilities with regard to different jobs. This information included employees' skills, experience, preference for routine or challenging work assignments, and standards of work quality. Both the production jobs and employee attributes were selected on the basis of considerable study of actual manufacturing processes. Employee profiles were provided at the start of the simulation but participants could refer to this information when carrying out the decision task to allocate employees to jobs.

As well as allocating employees to jobs, participants were required to make decisions about the use of various motivational factors to optimize the group's performance. They had to decide how to use goals, instructive feedback, and social rewards to enhance the job accomplishments of each employee. For each of these motivational factors, participants were provided with a set of options representing the types of actions that managers could take in an actual organisation. A mathematical model was used to calculate the hours taken to complete a production order on the basis of participants' decisions about allocation of employees to jobs, setting of goals, use of feedback and use of rewards. The performance of the work group on each trial was reported to participants at the end of that trial as a percentage of a preset standard number of hours to complete each manufacturing order. The performance standard, which was based on information from a pretest of performance attainments on the task, was set at a level that was moderately difficult to fulfill. A more detailed description of this model can be found in Wood and Bailey (1985).

In summary, to optimize performance of the simulated organisation the participants were managing they had to match employee attributes to job requirements and to master a complex set of decision rules on how best to guide and motivate their employees. To discover the rules they had to test options, cognitively process the outcome feedback information of their decisional action, and continue to apply analytical strategies in ways that would reveal the governing rules. To complicate matters further, the motivational factors involved both non-linear and compound rules, which are especially difficult to learn. Knowing rules does not ensure optimal implementation of them. Participants also had to gain proficiency in tailoring the application of the rules to individual employees and to apply them in concert to achieve desired results.

After participants had read the introductory information, they performed the simulation at a computer terminal. They entered all of their decisions on the keyboard of a personal computer. Participants received information about the weekly production orders, the roster of available employees and feedback on the organisation's level of productivity via the computer screen. After the final trial the experimenter provided participants with a full explanation of the nature and purpose of the study.

All data were collected during the performance of the simulation, which included a total of 12 trials. Self-report measures were presented on the monitor following trials 6 and 12. Participants recorded their responses on the keyboard. The first assessment was conducted after the sixth trial so that participants would have some experience with the simulation before being asked to judge their perceived efficacy and to set goals for themselves.

Error feedback conditions

Participants were allocated at random to one of the three error feedback groups. All groups completed the same task and self-assessment questions but each group differed in the nature of the feedback that was provided by the computer during each trial on the simulation.

Control condition: outcome feedback

This group received normal outcome feedback including information about the performance of individual employees and the work group on each trial.

After completion of each trial, the computer provided participants with feedback that included a statement as follows:

> "Your department produced the special order in 144% of estimated time"

plus a report on the actual hours taken by each employee and by the overall departmental work group. Participants in the outcome feedback condition received no information on the location of errors or any other supplementary information that might have guided their search for corrective actions.

Signal error feedback

This group received the outcome feedback described above supplemented with feedback that signaled the location of their errors and the magnitude of their impact. Participants receiving signal error feedback were informed that different choices on up to four listed variables would have resulted in improved performance. The four variables were listed in order of importance, starting with the decision variable for which the correction of errors would have the greatest impact on performance.

After completion of each trial, the computer provided participants in the signal error feedback group with information as follows:

> "Your department produced the special order in 144% of estimated time.
>
> If you had made different choices for Production Targets and Job Assignments your team's performance would have been about 30% better.
>
> Job assignments would have made more difference than production targets on this order."

The signal error feedback group therefore received guidance in their exploratory search for corrective actions, but still had to use the signal error feedback to infer what corrective action they should take in order to improve their performance.

Diagnostic feedback

The diagnostic feedback group received feedback after each trial as to which would have been the optimal choices to make on the trial just completed. This group also received outcome feedback about overall work group performance.

After completion of each trial, the computer provided participants with information similar to the following:

> "Your department produced the special order in 144% of estimated time.
>
> If you had made these choices:

Person	Assignment to Job	Production Target	Feedback	Reward
Bert	Finished Goods Warehouse	75%	Advise	None
Dave	Assembly	75%	None	None
Janice	Upholstery	75%	Advise and discuss	None
Hilary	Sewing Room	75%	Discuss	None
Evelyn	Fabric cutting	75%	Advise	None

> Your team's performance would have been about 30% better.
>
> Job assignments would have made more difference than production targets on this order."

Thus, the feedback in the diagnostic condition was highly specific. It identified the location of errors and directed the process of identifying the correct responses.

Measures

Learning

At the end of the task, participants completed a 24-item quiz which examined level of declarative knowledge about the decision rules that governed performance on the simulation. Scores on this quiz were the number of items correctly answered. All items were to be answered 'True' or 'False'. Examples of items include:

- “When an employee is performing badly, setting a difficult goal lowers their performance in the following week.”
- “Advising on performance level in relation to estimated hours is the most specific form of feedback available.”
- “It is generally better to give high rewards for any improvement in performance.”

Performance

Performance was measured in terms of the total number of hours taken by the group of employees to complete each weekly order. The simulation model automatically calculated the number of production hours for each trial on the basis of participant’s job allocations and selections of motivational factors. The fewer the production hours, the better the participant’s managerial decision making. Levels of performance attained by participants are reported as percentages of the standard, reverse scored so that a higher score indicated better performance.

Performance data were analyzed in two ways: the average performance of each participant on each of two blocks of six trials, and the participants’ maximum score on each block of trials. The maximum score data was found to be preferable as there were four distinct outliers within the diagnostic feedback group. Subsequent analysis of experimenters’ notes revealed that these four participants, for whom performance was exceptionally poor, had indicated after the experimental session that they had not realized there was a ‘help’ facility included in the simulation. In order to minimize the impact of these outliers, performance was measured in terms of each participant's maximum score in block 1, in block 2 and overall.[2]

Analytic strategy

The adequacy of participants' analytic strategy was derived from participants' decisions regarding job assignments and how they varied the motivational factors to discern the managerial rules across each block of trials. Analytic strategy scores were a count of the number of systematic tests that participants carried out in their attempts to determine how job allocations and motivational arrangements affected the performance of individual employees. The reported strategy scores were the sum of decisions across each block of 6 trials in which participants changed only a single factor (i.e. job allocation, goal level, instructive feedback, or social reward) for each individual employee. Changing more than one factor concurrently for a given employee is a deficient analytic strategy for testing hypotheses regarding the impact of motivational factors on performance because it confounds the contribution of factors to outcomes. Systematic analytic strategies require changing one factor at a time. Five systematic tests, one for each employee, could be made in each trial. Therefore, a participant's analytic strategy score across a block of six trials could range from 0 to 30.

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[2] This was in fact a conservative analytic approach as significance of results was markedly greater with the outliers deleted, despite the reduced n. For example, the ANOVA testing for differences between feedback conditions on performance, $F(2,45)= 3.20$, $P=.05$ becomes $F(2,41) = 10.74$, $p<.01$.

Exploration

Exploration was operationalized as the total number of factors changed for all employees in each trial without consideration of confounding variations. This quantity measure of decision-making activity equates movement across decision options with the exploration of the potential space defined by the full range of options for all decision variables.

Depth of processing

The time taken by each participant to enter their first decision for each trial on the keyboard *excluding* time spent reading feedback was used as a proxy for depth of processing of information. Time spent reading feedback was operationalized as the time between feedback appearing on the screen and the time participants hit a key to leave the feedback screen and re-enter the decision screen. Decisions could not be entered until participants had left the feedback screen. Observation of participants showed that all participants maintained their focus of attention towards the feedback screen when feedback was present. The time taken to complete each trial and the time spent examining the feedback were automatically recorded by the computer. Each of the three different forms of feedback presented different amounts of information and therefore participants in each of the three conditions were expected to differ in the time spent reading the feedback.

Perceived self-efficacy

Two forms of self-efficacy were measured: efficacy for achievement of different levels of performance outcomes and efficacy for the process of managing the simulation.

Outcome self-efficacy was recorded on a multi-item efficacy scale that described nine levels of production attainments, ranging from 30% better than the standard to 40% worse than standard production time. For each item, participants' first recorded whether or not they could perform at the level described (yes or no). On performance levels for which they answered 'yes', they were then required to record their confidence in their capabilities on a 10-point scale where 1 represented "very low confidence" and 10 "very high confidence". The strength of perceived self-efficacy was the sum of the confidence scores for the nine levels of performance. The internal reliability coefficients for the self-efficacy scores were acceptable for measures taken after both the first and second blocks of six trials (α_1= .84; α_2= .87).

Process self-efficacy items targeted the different decisions that had to be made in the management of the simulation, including perceived efficacy for placing employees in the correct job, setting appropriate targets, giving relevant feedback and giving appropriate rewards. Items were presented in the same format as for the outcome self-efficacy scale but the wording was changed to describe the four decision functions. Self-efficacy strength was the sum of the confidence ratings for the four items. Internal reliability coefficients for the self-efficacy scale were low for measures taken after the first block of six trials (α_1= .60) but acceptable after the second block of six trials (α_2= .83).

Self-set goals and goal commitment

On completion of each block of trials, participants answered questions presented on-screen about the level of performance they were personally aiming for in the succeeding block of trials. They selected their personal goal from nine levels of possible attainments ranging from 40% below the established standard to 30% above the established standard and from a tenth option of no particular one. The responses were scored on a scale of 1 to 10, in which 1 represented ‘no particular goals’; 2 represented a goal of 40% below the standard and 10 represented a goal of 30% above the standard, with 5 indicating that the goal was to achieve the standard level of performance.

Goal commitment was recorded on a single item scale of 1-10, with 1= “Not committed” and 10= “Very strongly committed”.

Intrinsic motivation

The items measuring intrinsic motivation were drawn from measures developed by Mossholder (1980) and Daniel and Esser (1980). The four items from the Mossholder scale assessed participant’s desire to continue working on the task; their level of interest in the activity; their perceived degree of challenge; and their satisfaction with the task. The items were anchored at 1 and 7 with “Not at all” and ‘To a large degree” respectively. The three items from the Daniel and Esser measure were 7-point semantic differential scales with the following anchors: “monotonous-exciting”, “boring-interesting”, and “stimulating-dull”. Principal components factor analysis revealed that the seven items from the combined scales loaded on a single factor with moderate inter-item reliability (α_1= .68; α_2= .79). Scale reliabilities could however be improved by the deletion of one item (the semantic differential item stimulating-dull). The intrinsic motivation scale therefore consisted of six items and scale reliabilities were acceptable after both blocks of trials (α_1= .86; α_2= .91).

Self-satisfaction (affect)

One item asked for participants' level of satisfaction with their prior performance. This item used a 9-point scale in which 1 = Highly satisfied, 5 = Neither satisfied nor dissatisfied and 9 = Highly dissatisfied. The coding was then reversed so that 1 = highly dissatisfied and 9 = highly satisfied.

Results

Table 6-1 shows the means, standard deviations and intercorrelations for all study variables. There were no significant differences between participants in the error feedback conditions for gender, age, prior experience or goal commitment[3].

The key set of correlations for testing the hypothesized relationships were the strategy, exploration and self-regulatory responses from block 1 with performance and learning in block 2. These are shown in the shaded area of table 6-1. The overall pattern of correlations was consistent with the hypotheses, with one exception. As hypothesized, strategy, process self-efficacy, self-set goals and satisfaction were positively correlated with performance, and strategy was positively correlated with learning. Contrary to expectations however, exploration in block 1 was strongly negatively associated with both performance in block 2, and with learning. Exploration was also negatively associated with strategy and with the self-regulatory processes of self-efficacy, self-set goals and satisfaction, while use of analytic strategy was positively correlated with the self-regulatory variables.

[3] Goal commitment was measured to ensure that differences in goal effects were due to goal level not to goal commitment. As goal commitment was not associated with any differences on other variables, it was not included in further analysis.

Table 6-1: Intercorrelations, means and standard deviations of Study 1 variables

Block 1 **Block 1**	1. Strategy	2. Exploration	3. Depth of processing	4. Outcome self-efficacy	5. Process self-efficacy	6. Self-set goals	7. Motivation	8. Satisfaction	9. Performance
1. Analytic strategy	*								
2. Exploration	-.62**	*							
3. Depth of processing	-.02	-.09	*						
4. Outcome self-efficacy	.06	-.22	.09	*					
5. Process self-efficacy	.29*	-.40*	.23	.25	*				
6. Self-set goals	.32*	-.37**	.02	.31*	.26	*			
7. Intrinsic motivation	-.01	-.05	.23	.01	.18	-.17	*		
8. Satisfaction	.15	-.40**	-.29*	.22	.29*	.03	.28	*	
9. Performance	.59**	-.68**	.12	.36*	.46**	.51**	-.04	.40**	*
Block 2									
10. Analytic strategy	.17	-.20	-.02	-.10	.25	-.07	.09	.17	.19
11. Exploration	-.62**	.78**	-.10	-.21	-.45**	-.40**	.00	-.37**	-.78**
12. Depth of processing	-.34*	.32*	.77**	-.03	-.04	-.23	.27	-.33*	-.23
13. Outcome self-efficacy	.08	-.45**	-.10	.69**	.33*	.34*	-.13	.34*	.54**
14. Process self-efficacy	.23	-.44**	.02	.33*	.54**	.27	-.08	.29*	.45**
15. Self-set goals	.32*	-.52**	-.13	.24	.33*	.71**	-.10	.35*	.67**
16. Intrinsic motivation	-.15	-.06	.12	-.05	.11	-.14	.66**	.18	-.07
17. Satisfaction	.32*	-.45**	.01	.38**	.41**	.41**	-.17	.20	.58**
18. Performance	.65**	-.78**	.10	.27	.41**	.50*	-.10	.35*	.96**
19. Learning	.34*	-.48**	.21	.13	.19	.25	.12	.16	.53**
Block 1Mean (SD)									
Outcome feedback	5.94 (2.70)	40.75 (9.48)	191.00 (77.41)	56.69 (17.00)	28.63 (6.51)	5.94 (2.29)	31.13 (6.36)	5.0 (2.50)	96.94 (16.78)
Signal error feedback	5.82 (3.23)	42.38 (13.83)	193.07 (76.09)	58.31 (15.01)	26.06 (4.86)	6.19 (1.60)	31.25 (5.51)	4.38 (1.89)	95.96 (15.72)
Diagnostic feedback	7.25 (3.04)	31.88 (10.97)	174.97 (81.61)	62.94 (19.00)	30.56 (5.37)	7.94 (2.26)	29.38 (5.46)	5.88 (1.41)	109.15 (17.95)

Table 6-1 (continued).

Block 2 **Block 2**	10. Strategy	11. Exploration	12. Processing	13. Outcome self-efficacy	14. Process self-efficacy	15. Self-set goals	16. Motivation	17. Satisfaction	18. Performance	19. Learning
10. Analytic strategy	*	-								
11. Exploration	-.39**	*								
12. Depth of processing	-.07	.25	*							.
13. Outcome self-efficacy	.12	-.49**	-.27	*-						
14. Process self-efficacy	.34*	-.59**	-.22	.57**	*					
15. Self-set goals	.14	-.65**	-.33*	.58**	.45**	*				
16. Intrinsic motivation	.11	-.08	.19	-.12	-.06	.04	*			
17. Satisfaction	.03	-.50**	-.29*	.53**	.49**	.58**	.02	*		
18. Performance	.18	-.81**	-.24	.49**	.39**	.70**	-.05	.60**	*	
19. Learning	-.24	-.42**	02	.26	.14	.38**	.10	.20	.58**	*
Block 2 Mean (SD)										
Outcome feedback	8.75 (4.93)	40.75 (22.18)	87.17 (35.23)	56.38 (20.19)	25.00 (10.07)	6.88 (2.31)	29.50 (8.64)	5.00 (2.00)	94.68 (23.43)	15.75 (2.54)
Signal error feedback	8.44 (4.00)	40.13 (19.89)	90.47 (38.31)	57.00 (22.26)	26.44 (8.20)	5.56 (2.25)	26.06 (7.57)	4.56 2.27)	91.13 (24.77)	15.13 (2.45)
Diagnostic feedback	10.75 (4.39)	25.38 (14.23)	66.61 (26.69)	65.44 (20.53)	32.63 (6.36)	8.06 (2.57)	28.25 (5.92)	6.19 (2.23)	109.11 (27.99)	16.19 (2.76)

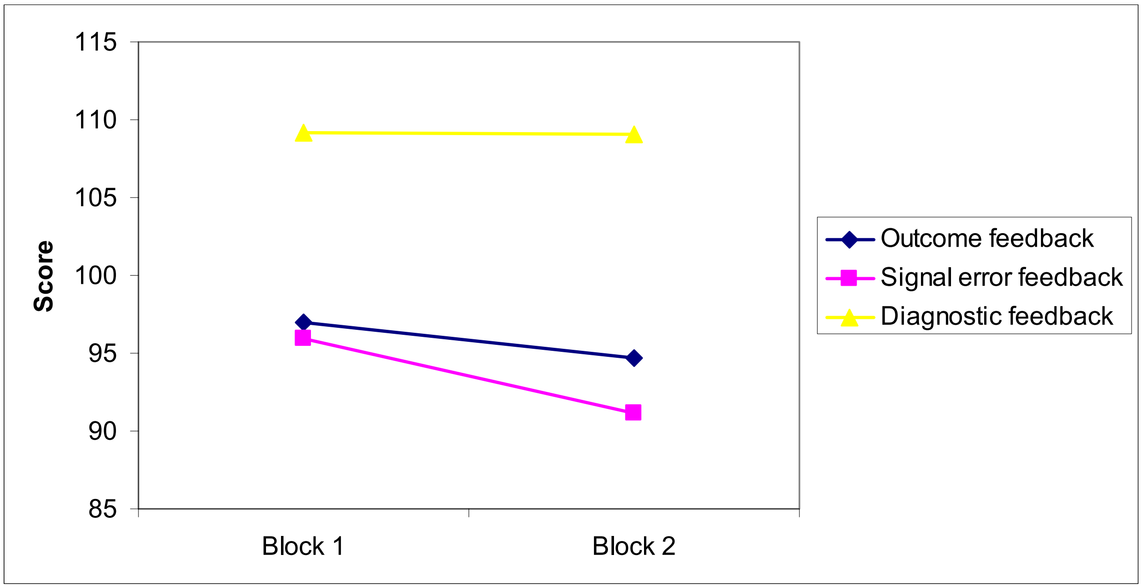
Effects of error feedback on performance and learning

Hypothesis 1A, which stated that diagnostic feedback would result in superior performance to signal error feedback and outcome feedback in the first block of trials, was supported, $F(2,45)=3.04$, $p=.05$. Participants in the diagnostic condition averaged 109% of standard across the 6 trials compared to 91% of standard for participants in the signal error feedback group and 95% in the outcome feedback group.

A 2 x 3 repeated measures ANOVA was conducted to test Hypothesis 1B, which stated that diagnostic feedback and signal error feedback would produce superior performance to outcome feedback on the second, but not the first, block of trials. This hypothesis was not supported as signal error feedback participants failed to improve their performance in block 2. However overall there was a significant difference in the performance levels of the three feedback groups, $F(2,45)=3.20$, $p=0.05$. Figure 6-1 shows that the main source of the effect was higher performance by the diagnostic feedback group compared to the signal error and outcome feedback groups. Post-hoc tests showed a significant difference between diagnostic feedback and the outcome and signal error feedback groups combined for performance ($t=2.55$, 46df, $p<.05$) but no significant difference for performance between signal error and outcome feedback groups.

Hypothesis 1C was not supported. Participants in the different feedback conditions did not differ significantly in their conscious recall of the decision rules that guided performance on the simulation, as assessed by the post-task quiz. Participants in all three groups answered

Figure 6 - 1: Performance in each block of trials.



approximately 63% of the questions correctly. Variations in performance on block 1 and block 2 were both significantly related to learning (r=.53, p<.01 and r=.58, p<.01 respectively).

Effects of error feedback on cognitive processes

Hypothesis 2 proposed that diagnostic feedback would facilitate certain cognitive processes and inhibit others more than would signal error or outcome feedback. This hypothesis was supported for analytic strategies and for exploration, but not for depth of processing.

Figure 6-2 shows the levels of effective analytic strategy for each group in each block of trials. As predicted, the diagnostic feedback group used more effective analytic strategies than did the other two groups (t=2.06, 46df, p<.05). Overall the use of effective analytic strategies increased from the first to the second block of trials, $F(1,45)=16.67$, $p<.05$.

Exploration was indexed by the number of decisions made by participants. As shown in Figure 6-3, the diagnostic feedback participants used significantly less exploration in both block 1, $F(2,45)=3.82$, $p<.05$, and block 2, $F(2,45)=3.34$, $p=.05$, than participants in the signal error and outcome feedback groups. The latter two groups did not differ from one another. Exploration was negatively associated with performance in block 1 (r= -.68, $p<.05$) and block 2 (r= -.81, $p<.05$) and with learning (r= -.47, $p<.05$).

Hypothesis 2 was not supported for the depth of processing measure. The amount of time participants spent making their decisions after reading the feedback became faster from the first to the second block of trials, $F(1,45)=165.93$, p<.05, but there was no significant effect

Figure 6 - 2: Use of analytic strategies

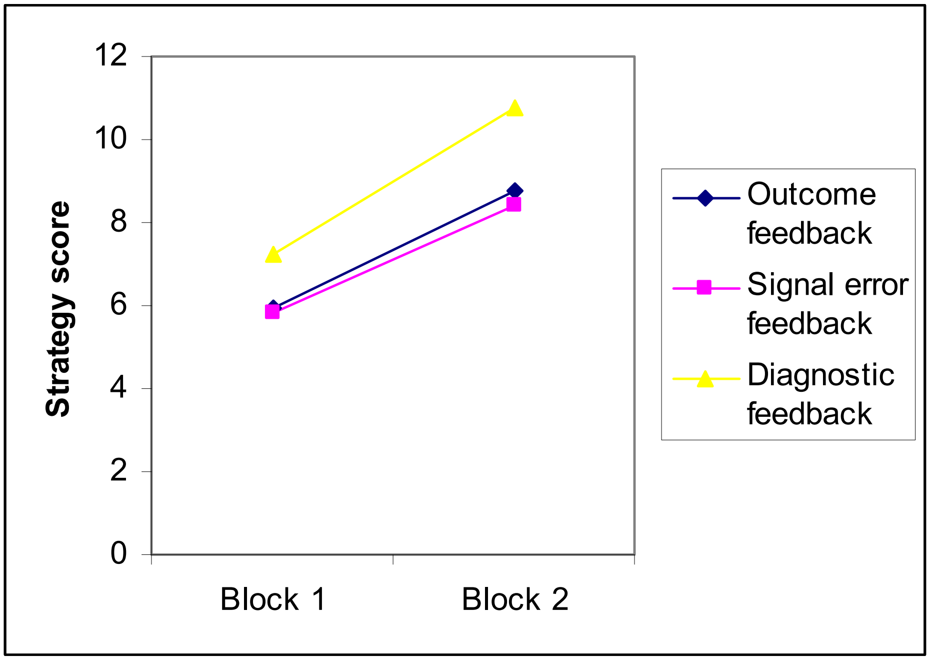
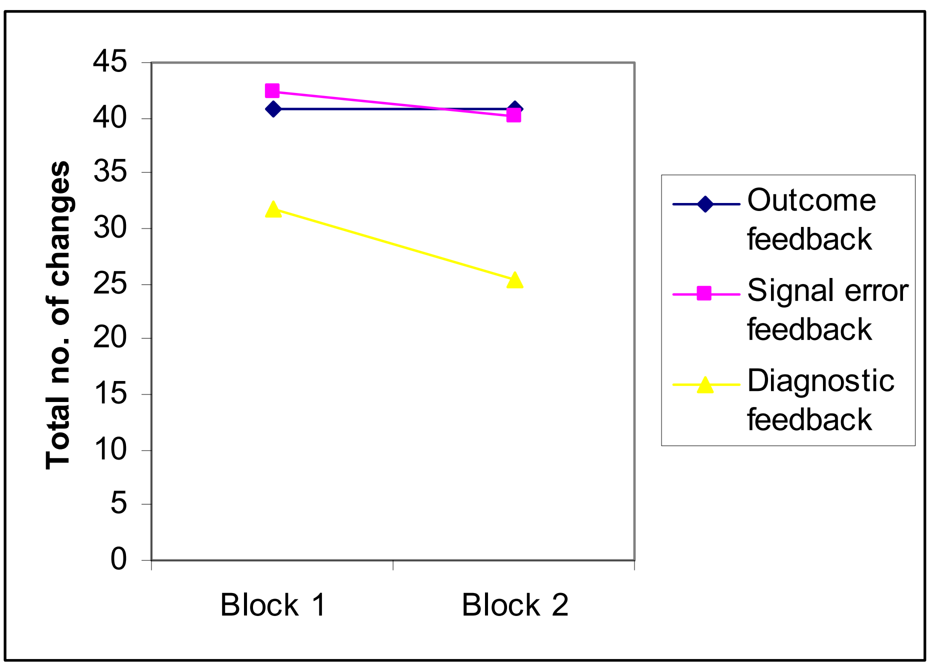


Figure 6 - 3: Exploration



for feedback type (see Figure 6-4). As the diagnostic feedback condition provided participants with more information than the signal error condition, we checked to see if participants in the diagnostic feedback condition spent more time looking at the feedback and this in fact was the case, but only for the first block of trials (t=2.62, 30df, p<.01). There was no significant difference between groups in the time spent looking at feedback in the second block of trials (see Figure 6-5).

Effects of error feedback on self-regulatory processes

There was partial support for hypothesis 3, which predicted that diagnostic feedback and signal error feedback would lead to stronger self-efficacy, higher self-set goals, greater satisfaction and more intrinsic motivation than outcome feedback. Diagnostic feedback participants had greater process self-efficacy, set higher goals and reported greater satisfaction than their counterparts in the outcome and signal error feedback conditions. The different feedback interventions had no effect on intrinsic motivation.

The type of feedback received influenced the levels of process self-efficacy but not outcome self-efficacy. There was a significant difference in participants' process self-efficacy, $F(2,45)=3.68$, p<.05, as shown in Figure 6-6. The diagnostic feedback group showed higher process self-efficacy than the other two groups (t=2.73, 46df, p<.05). Detailed diagnostic feedback did not appear to enhance self-efficacy for the production of specific task outcomes but it was associated with higher self-efficacy for those task decisions specifically

Figure 6 – 4: Depth of processing in each block.

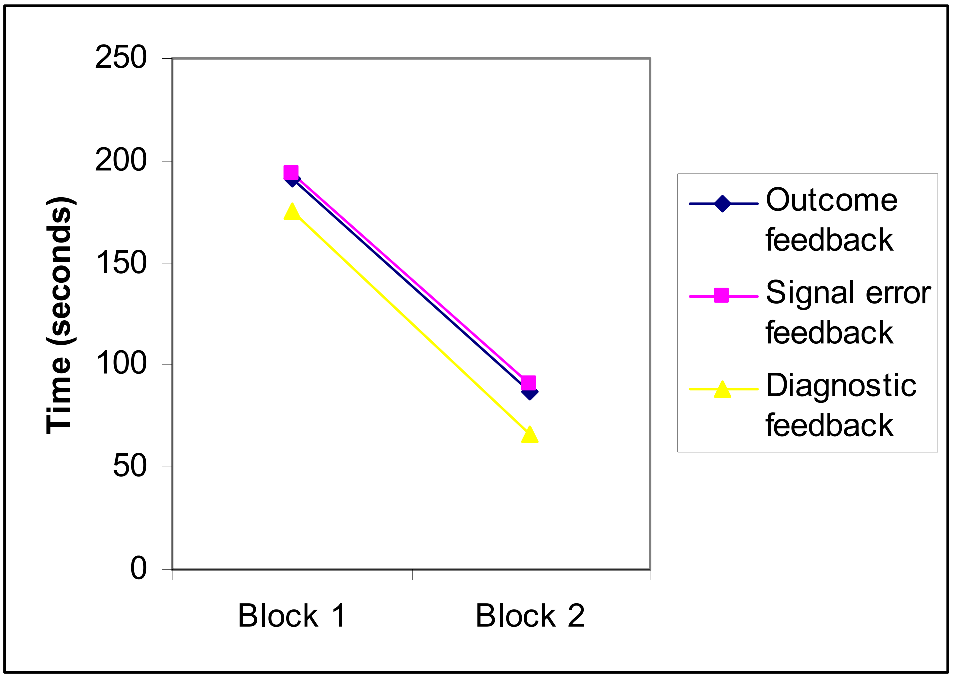
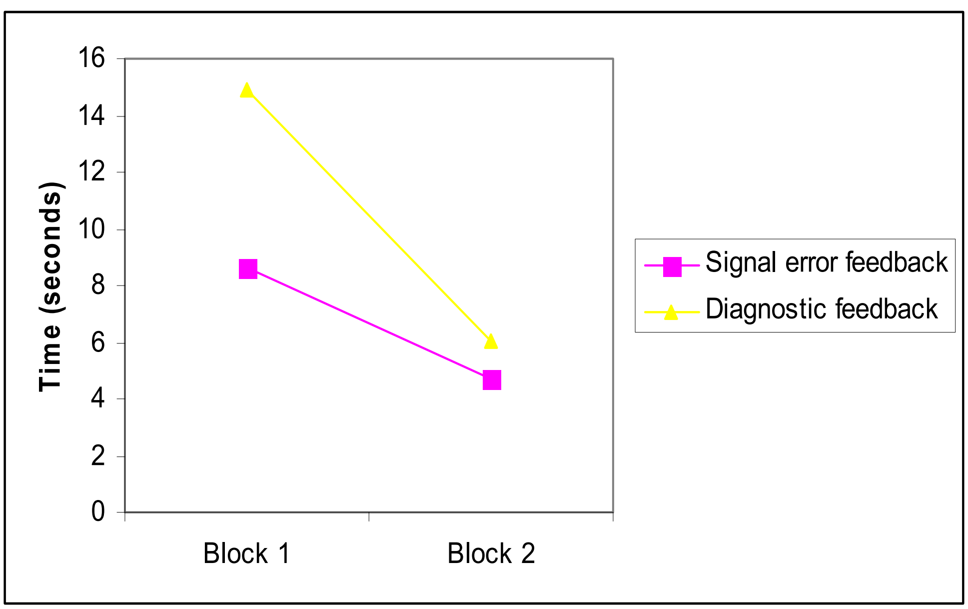


Figure 6 - 5: Time spent looking at feedback for signal error and diagnostic feedback conditions.



covered by the feedback.

Outcome feedback participants and signal error participants set themselves lower goals than did participants in the diagnostic feedback condition, $F(2,45)=4.65$, $p<.05$; see Figure 6-7. There was also a significant interaction between feedback type and assessment phase, $F(2,45)=3.13$, $p=.05$. Between the first and second assessment phases, the self-set goals in the outcome feedback condition tended to increase while signal error participants decreased the goals that they set themselves. Diagnostic feedback participants' self-set goals, already high, remained unchanged.

Figure 6-8 shows how diagnostic feedback participants reported greater satisfaction with their performance than the other two groups across both assessment phases, $F(2,45)=4.17$, $p<.05$.

The predicted main effect for feedback type on intrinsic motivation was not supported. Repeated measures ANOVA showed that intrinsic motivation declined from the first to the second assessment phase across all three feedback groups, $F(2,45)=5.82$, $p<.05$. There was a marginally significant interaction between feedback condition and assessment phase, $F(2,45)=3.06$, $p=.06$. Over time, intrinsic motivation declined for the outcome feedback and signal error feedback groups but remained largely unchanged for the diagnostic feedback group (see Figure 6-9).

Figure 6 - 6: Process self-efficacy scores

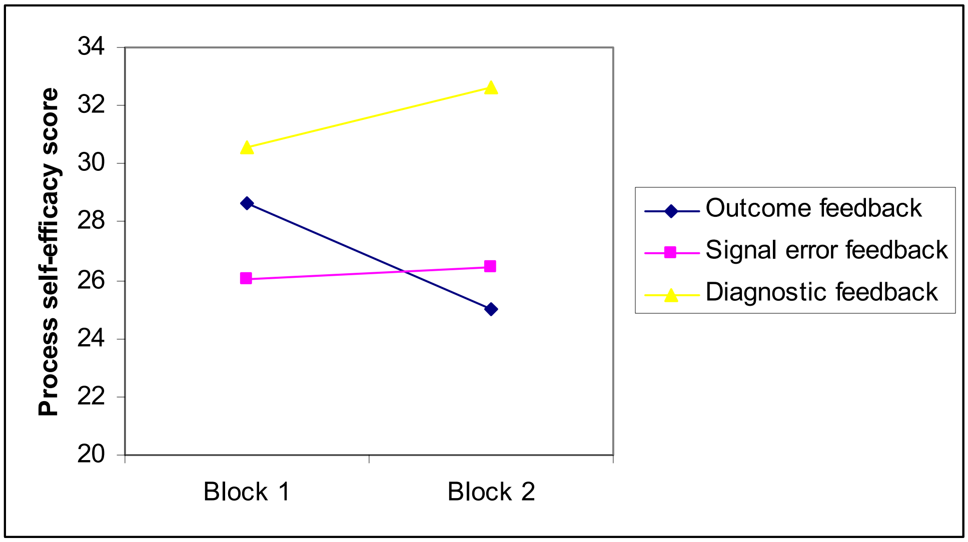


Figure 6 - 7: Self-set goals

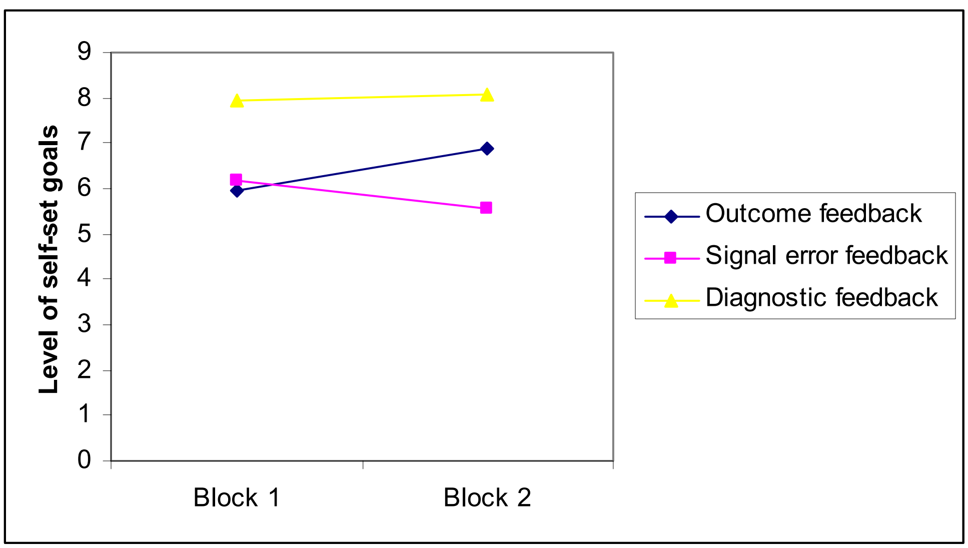


Figure 6 - 8: Satisfaction.

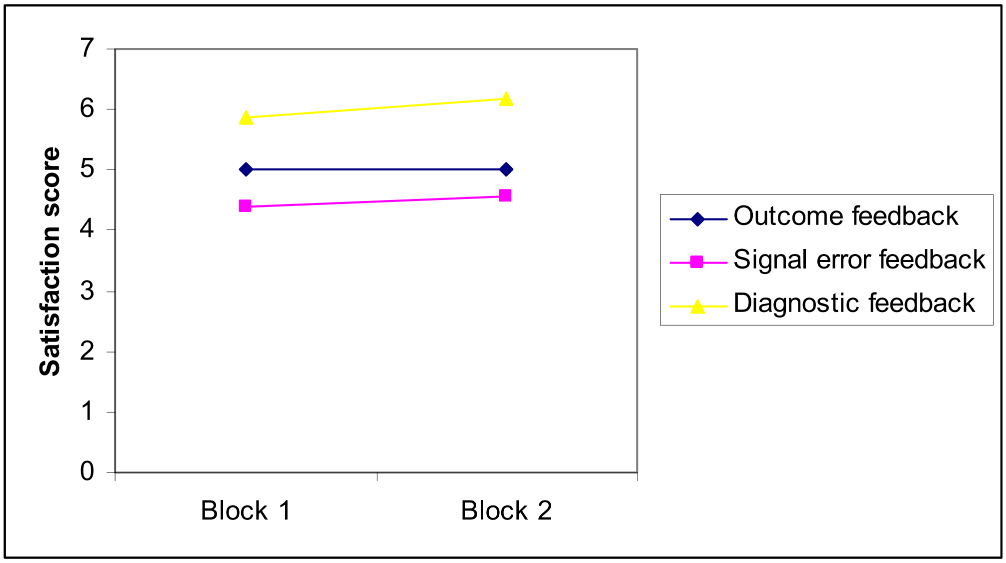
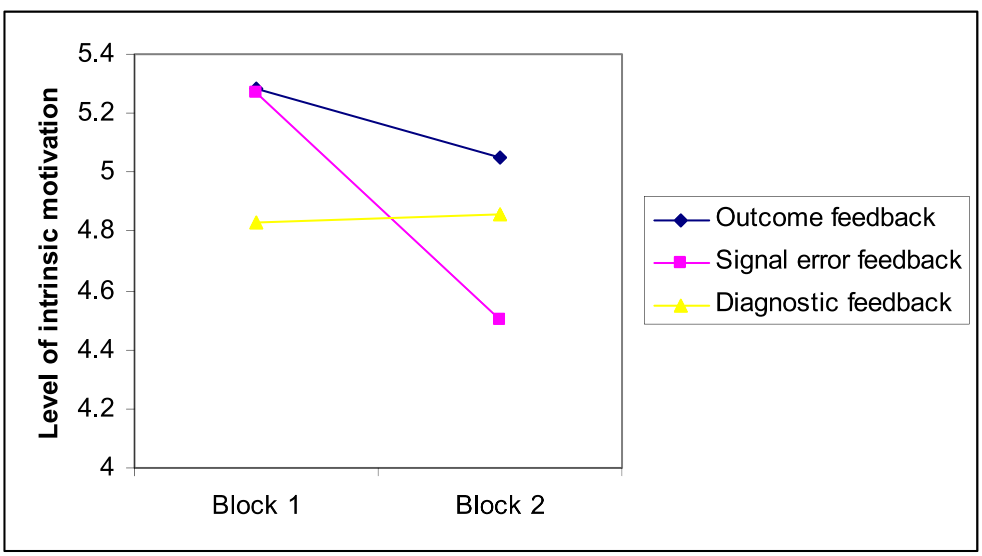


Figure 6 - 9: Intrinsic motivation



Mediation analyses

Hypotheses 4 and 5, respectively, stated that the cognitive and self-regulatory processes would mediate the effects of feedback on performance and learning. Hypothesis 4 was supported for exploration and strategy but not for depth of processing. Hypothesis 5 was supported for process self-efficacy, satisfaction and self-set goals.

The mediational hypotheses were tested on block 2 performance, with feedback type as the antecedent variable. To ensure the proper causal ordering, the self-regulatory variables measured at the first assessment phase and the cognitive variables from block 1 were used as the mediators in the analyses. For the purposes of the mediation analysis, feedback type was dummy coded so that outcome and signal error feedback = 0 and diagnostic feedback =1. The mediated regression procedure recommended by Baron and Kenny was used (Baron & Kenny, 1986). As shown in model 1, the dummy coded feedback variable had a significant impact on performance (b=.30, $p<.05$). The hypothesized mediators tested were those which had significant relations with Block 2 performance (see Table 6-1). These were exploration (model 2), strategy (model 3), process self-efficacy (model 4), satisfaction (model 5) and goals (model 6). Table 6-2 reports the mediated regression analyses for effects on block 2 performance.

In all models, the introduction of the single mediator reduced the impact of the feedback type on performance from significance to non-significance. Exploration and analytic strategy each fully mediated the impacts of diagnostic feedback on performance. Tests of the individual self-regulatory mediators showed that self-efficacy, self-satisfaction and self-set goals mediated the effect of feedback type on performance. Tests of significance for the changes in beta supported the mediation role of exploration and self-set goals (see Table 6-2). With all possible mediation variables included in the regression (model 7), the impacts of feedback type on performance were fully mediated. In the full model, the significant mediational pathways, after controlling for the effects of all other mediators, were exploration (beta=-.40), strategy (beta=.29) and goals (beta=.26). The R^2 change following the introduction of the mediators indicates that, in addition to the mediation effects, the mediator variables had direct additive effects on performance.

Table 6-2: Mediation of cognitive and self-regulatory processes on the relationship between error feedback and performance.

Dependent variable	Independent variables	beta	Change in beta[4]	Sobel test[5]	R^2 change	df
Model 1						
Performance	Feedback type	.30*			.09	1,46
Model 2						
Performance	Feedback type	.02	93%	2.55**	.54	2,45
	Exploration	-.73***				
Model 3						
Performance	Feedback type	.16	47%	1.46	.45	2,45
	Strategy	.61***				
Model 4						
Performance	Feedback type	.21	30%	1.51	.21	2,45
	Self-efficacy	.36*				
Model 5						
Performance	Feedback type	.22	27%	1.41	.17	2,45
	Satisfaction	.29*				
Model 6						
Performance	Feedback type	.12	60%	2.18*	.26	2,45
	Goals	.45**				
Model 7						
Performance	Feedback type	-.09	70%		.67	6,41
	Exploration	-.40**				
	Strategy	.29*				
	Self-efficacy	.07				
	Satisfaction	.14				
	Goals	.26*				

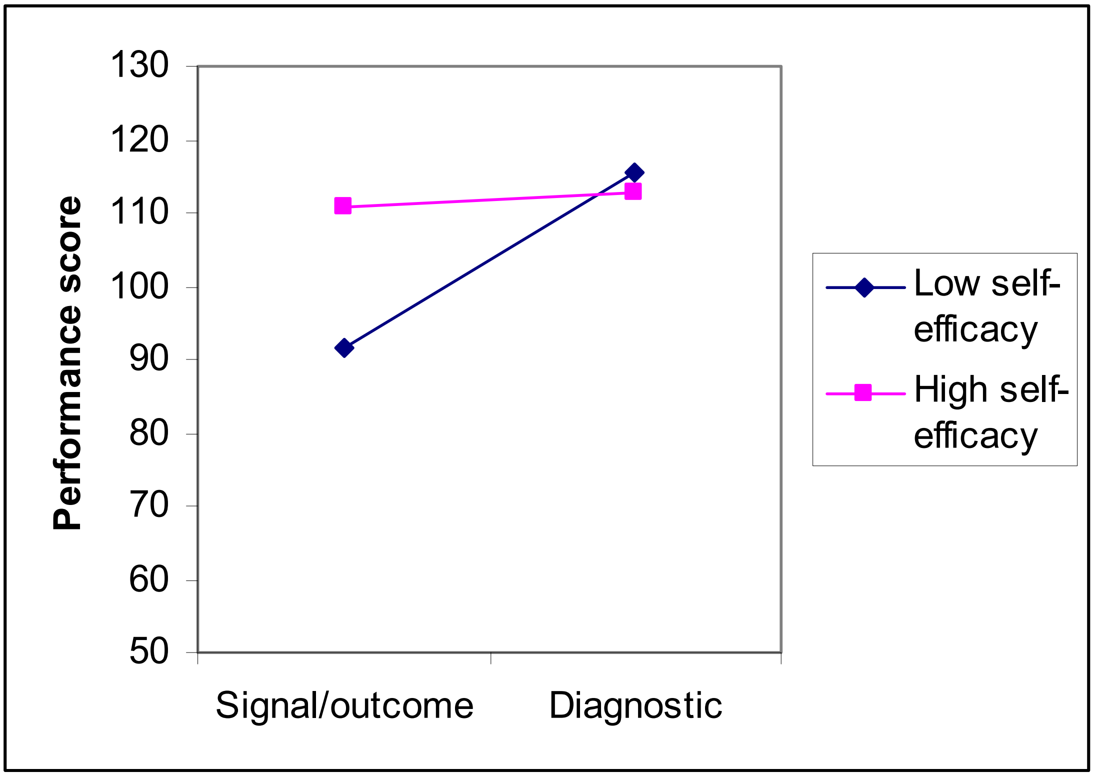
[4] Percentage attenuation of the feedback type beta following the introduction of the mediator variables.
[5] Tests whether the indirect effect of the IV on the DV via the mediator is significantly different from zero. There is no straightforward way to test for significance in the full model (Model 7).

Interaction effects

Hypothesis 6, which stated that the relationship of feedback type to performance and learning would be moderated by participants' self-efficacy, was tested using moderated regression analysis. As prior analysis had indicated no significant differences between outcome and signal error feedback, the test of interaction effects was for diagnostic feedback vs. the other two conditions combined. Dummy coding was used in which outcome and signal error feedback = 0 and diagnostic feedback =1. The predictors in the regression analysis were the dummy coded feedback type and process self-efficacy, measured at the first assessment phase. The interaction term was the product of process self-efficacy and the dummy coded feedback term. Process self-efficacy was centered to remove scale effects in the interpretation of the *b* (Aitken & O'Driscoll, 1998). Performance in block 2 was the outcome variable.

The self-efficacy x feedback interaction term failed to reach significance at the .05 level but was significant at the .10 level (*b*=-2.33, beta=-.285, p=.09). Figure 6-10 shows the plots of block 2 performance on the task by participants in the outcome and signal error conditions vs. the diagnostic feedback condition who had either high or low self-efficacy. Participants with high self-efficacy demonstrated high levels of performance under all feedback conditions. Participants with low self-efficacy performed poorly under impoverished feedback conditions (outcome feedback and signal error feedback) but matched their high self-efficacy counterparts in the diagnostic feedback condition.

Figure 6-10: Interaction effects of feedback type and self-efficacy on performance.



Discussion

There was support for the hypothesized benefits of diagnostic feedback but not signal error feedback. Participants receiving diagnostic feedback outperformed their counterparts who received either signal error feedback or outcome feedback in both blocks of trials. The performance levels of participants who received signal error feedback did not differ from those who received outcome feedback. Diagnostic feedback also prompted better use of analytic strategies, less exploration, stronger process self-efficacy, higher self-set goals and greater satisfaction with performance than did the other two forms of feedback. However diagnostic feedback produced no equivalent advantage in the conscious recall of the decision rules that determined good task performance.

It was hypothesized that participants receiving signal error feedback would improve their performance over time but the results did not support this hypothesis. In both blocks of trials the signal error participants showed high levels of exploration and poor use of analytic strategies, and consequent poor performance. It was apparent that good performance required effective analytic strategies rather than unsystematic exploration, and only diagnostic feedback facilitated the use of a systematic strategy and minimized the tendency of participants to explore the problem space in an unstructured and unproductive fashion.

The present study did not find support for the hypothesized benefits of unsystematic exploration on performance and learning. Although signal error feedback prompted participants to explore the problem space, unsystematic exploration was negatively associated with both performance and learning. In the absence of detailed feedback, exploration did not provide participants with the necessary information to identify the decision rules underpinning good performance. Good task performance required systematic testing of decision alternatives, which provided feedback that could be used to interpret the impacts of different choices.

The effects of feedback on performance were fully mediated by cognitive and self-regulatory processes. The main mediation pathways with all possible pathways combined were exploration, strategy and self-set goals. Unsystematic exploration had a powerful negative effect on performance whereas analytic strategy and self-set goals were significant positive mediators. Participants' process self-efficacy also moderated the relationship of feedback type to performance. The harmful effects of impoverished feedback were most apparent in participants with low self-efficacy for the task. Participants who believed they could do the task persisted in using systematic strategies in spite of less diagnostic feedback but for those who were less confident, diagnostic feedback was essential for good performance.

None of the three forms of error feedback resulted in superior learning. It is possible that the lack of learning benefits for diagnostic and signal error feedback were due to different effects of the two types of feedback. Diagnostic feedback included information on the actions that could be used to achieve better performance on each trial rather than an explanation of the underlying rationale. This resulted in fewer but more systematic decisions being made and better performance, but no better understanding of the task. Signal error and outcome feedback resulted in more unsystematic decision making, likely in itself to result in increased cognitive load which would impair learning. Signal error feedback was therefore not effective in building either good task performance or good learning.

The findings indicate that diagnostic feedback facilitates more systematic and strategic approaches to the task and produces more productive self-regulatory responses to the task challenges than do signal error or outcome feedback. Signal error feedback was ineffective in that it was likely to prompt high levels of unstructured exploration rather than systematic problem-solving and did not help participants to develop self-efficacy for the task. However signal error feedback is very common in learning tasks and so it is important to identify ways in which its effectiveness can be enhanced. Research into error management has identified the positive reframing of errors as a useful technique for encouraging learning from errors, but the interactions of error framing and types of error feedback, and their joint effects on performance and learning, have not been studied. Study 2 was undertaken to investigate the extent to which positive error framing could improve the effectiveness of signal error feedback.

Chapter 7: Study 2 - Error framing and error feedback

Introduction

Signal error feedback which indicates that an error has been made but provides no diagnostic information is the most common form of error feedback available. It is frequently argued that the self-guided analysis and inferences required to convert signal error feedback into correct adaptive responses to errors will lead to superior learning (e.g. Ivancic, 1998). Given the claimed benefits of signal error feedback for learning, it is appropriate to examine whether there are ways to enhance the value of signal error feedback to learners of a complex novel task.

The potential benefits from extended cognitive processing stimulated by signal error feedback may be offset by the negative self-evaluations that result from error feedback. This argument is consistent with the results of Study 1 in which both signal error and outcome feedback were associated with lower levels of self-efficacy, self-set goals and satisfaction. These findings are also consistent with the arguments in the error management literature that errors can be dysfunctional unless framed positively (Frese, 1997; Frese, Debowski & Wood, 1997).

The aim of Study 2 was to establish whether the positive framing of errors can mitigate negative self-evaluative reactions arising from signal error feedback and thereby enhance its effectiveness. Diagnostic feedback was used as the comparison condition for this study, as diagnostic feedback was shown in Study 1 to produce more effective strategies and performance and equivalent levels of learning to signal error feedback. Study 2 aimed to investigate whether error framing could make signal error feedback more effective than diagnostic feedback, and to investigate the impacts of error framing on diagnostic feedback itself.

Aim

The current study aims to explore a positive error frame (error management, or EM) compared to a negative error frame (error avoidance, or EA) approach as a means to enhance the value of signal error feedback. The research question for the second study was: "To what extent do error management instructions enhance the value of signal error feedback compared to error avoidance instructions?"

Hypotheses

The hypotheses tested in this study were as follows:

> *Hypothesis 1:* Error framing will interact with the effects of error feedback, such that signal error feedback will result in higher levels of performance and learning with positive error framing than with negative error framing. Performance and learning of participants receiving diagnostic feedback will not be affected by error framing.
>
> *Hypothesis 2*: Error framing will interact with the impacts of error feedback such that signal error feedback will result in better strategy, less unsystematic exploration and more depth of processing with

positive error framing than with negative error framing. Strategy, exploration and depth of processing for participants receiving diagnostic feedback will not be affected by error framing.

Hypothesis 3: Error framing will interact with the impacts of error feedback such that signal error feedback will result in better self-efficacy, goals, intrinsic motivation and affect (satisfaction) with positive error framing than with negative error framing. Self-efficacy, goals, intrinsic motivation and affect for participants receiving diagnostic feedback will not be affected by error framing.

Hypothesis 4: Strategy, exploration and depth of processing will mediate the relationship between error feedback and error framing, and performance and learning outcomes.

Hypothesis 5: Self-efficacy, self-set goals, intrinsic motivation and affect (satisfaction) will mediate the relationship between error feedback and error framing, and performance and learning outcomes.

Hypothesis 6a: The relationship of error feedback and error framing to performance will depend upon participants' self-efficacy. Participants with high self-efficacy will show similar performance regardless of error feedback type and error framing, whereas participants with low self-efficacy will show superior performance when receiving diagnostic feedback or error management framing than when receiving signal error feedback or error avoidance framing.

Hypothesis 6b: The relationship of error feedback and error framing to performance will depend upon participants' use of analytic strategies. Participants with good strategies will show similar performance regardless of error feedback type and error framing, whereas participants with poor strategies will show superior performance when receiving diagnostic feedback or error management framing than when receiving signal error feedback or error avoidance framing.

Hypothesis 7a: The relationship of error feedback and error framing to learning will depend upon participants' self-efficacy. Participants with high self-efficacy will show similar learning regardless of error feedback type and error framing, whereas participants with low self-efficacy will show superior learning when receiving diagnostic feedback or error management framing than when receiving signal error feedback or error avoidance framing.

Hypothesis 7b: The relationship of error feedback and error framing to learning will depend upon participants' use of analytic strategies. Participants with good strategies will show similar learning regardless of error feedback type and error framing, whereas participants with poor strategies will show superior learning when receiving diagnostic feedback or error management framing than when receiving signal error feedback or error avoidance framing.

Method

As in Study 1, participants completed the Furniture Factory simulation. Participants received either signal error feedback or diagnostic feedback in conjunction with an error management (EM) or an error avoidance (EA) frame. This 2 x 2 design resulted in four groups as follows:

- EM/signal error feedback (n=19),
- EM/diagnostic feedback (n=19),
- EA/signal error feedback (n=19),
- EA/diagnostic feedback (n=18).

Participants were randomly allocated to one of the four groups.

Participants

Participants were 39 men and 36 women participating in undergraduate classes in Commerce, Economics and Materials Science. Their average age was 19.7 years (SD = 3.78).

The task

All data were collected during the performance of the Furniture Factory simulation, which included a total of 12 trials. Self-report measures were presented on the monitor following trials 6 and 12. Participants recorded their responses on the keyboard. The first assessment was conducted after the sixth trial so that participants would have some experience with the simulation before being asked to judge their perceived efficacy and to set goals for themselves.

Error feedback conditions.

Two error feedback conditions were used. These were the signal error and diagnostic feedback conditions and the manipulations for each were exactly the same as those described for Study 1.

Error framing conditions.

At four points during the simulation participants were provided with on-screen instructions designed to emphasize either error management or error avoidance approaches.

The error management heuristics used to positively frame errors in this study were based upon those reported and validated in previous research (Dormann & Frese, 1994; Frese, 1995; Frese & Altmann, 1989). The error avoidance heuristics were developed for this study and parallel those used in the error management condition.

Error management framing.

The error management participants received the following instructions, which were taken from Frese (1995).

1. Remember, errors are a natural part of learning. They point out what you can still learn.

2. When you make an error in this simulation, look at it as help to improve your performance.

3. Errors teach you what you don't know. It is best to make some errors so that you can learn more.

4. Look at the screen so you can see what is changing there and improve your performance.

These instructions were all presented before block 1. The first two instructions were repeated midway through block 1; the second pair was presented at the start of block 2 and the first pair was again presented midway through block 2.

Error avoidance framing.

Heuristics to negatively frame error for the error avoidance condition were developed to parallel those used in the error management condition. These instructions were as follows:

1. Remember, errors interrupt learning. Avoiding mistakes is the best way to learn this task.

2. When you make an error in this simulation, it has a bad effect on your performance.

3. Errors are a trap to be avoided. Don't waste time and resources by making the wrong choices.

4. Be attentive! Control what is happening in your work group.

All instructions were presented before block 1. Instructions 1 and 2 were repeated midway through blocks 1 and 2. Instructions 3 and 4 were repeated at the start of Block 2.

Measures

All measures were as described for Study 1. The internal reliability coefficients for measures taken after the first and second block of trials respectively were as follows: outcome self-efficacy (α_1= .78; α_2= .86), process self-efficacy (α_1= .79; α_2= .80) and intrinsic motivation (α_1= .91; α_2= .94).

Results

Table 7-1 shows the intercorrelations, means and standard deviations for all study variables. There were no significant differences between participants in the four groups in terms of age, level of prior managerial experience, gender, or goal commitment[6].

As for Study 1, the principal correlations for testing the hypothesized relationships were the strategy, exploration and self-regulatory responses from block 1 with performance and learning in block 2. These are shown in the shaded area of table 7-1. The overall pattern of correlations was similar to that in Study 1. Strategy, self-efficacy, self-set goals and satisfaction were positively correlated with later performance. As in Study 1, exploration in block 1 was negatively associated with both performance in block 2, and with learning. Exploration was also negatively associated with strategy and with the self-regulatory processes of self-efficacy, self-set goals and satisfaction, while use of analytic strategy was positively correlated with the self-regulatory variables.

---

[6] As in Study 1, goal commitment was measured to ensure that differences in goal effects were due to goal level not to goal commitment. As goal commitment was not associated with any differences in other variables, it was not included in any further analysis.

Table 7- 1: Intercorrelations, means and standard deviations of study variables

Block 1	1. Analytic strategy	2. Exploration	3. Depth of processing	4. Outcome self-efficacy	5. Process self-efficacy	6. Self-set goals	7. Intrinsic Motivation	8. Satisfaction	9. Performance
Block 1									
1. Analytic strategy	*								
2. Exploration	-.43**	*							
3. Depth of processing	-.07	.21	*						
4. Outcome self-efficacy	.33**	-.53**	-.05	*					
5. Process self-efficacy	.30**	-.51**	-.05	.71**	*				
6. Self-set goal	.22	-.36**	-.12	.29*	.27*	*			
7. Intrinsic motivation	.01	-.09	.19	.16	.19	.20	*		
8. Satisfaction	.41**	-.47**	-.16	.50**	.56**	.31**	.16	*	
9. Performance	.49**	-.61**	.09	.56**	.53**	.32**	.08	.50**	*
Block 2									
10. Analytic strategy	.15	-.23*	.16	.10	.10	.11	.16	.20	.33**
11. Exploration	-.44**	.74**	.08	-.47*	-.45**	-.20	.01	-.33**	-.62**
12. Depth of processing	-.19	.43**	.59**	-.30**	-.25*	-.18	.13	-.27*	-.27*
13. Outcome self-efficacy	.48**	-.59**	-.02	.85**	.74*	.34**	.12	.54**	.68**
14. Process self-efficacy	.35**	-.55**	-.03	.65**	.84**	.25**	.23*	.48**	.49**
15. Self-set goal	.33**	-.50**	-.04	.46**	.42**	.71**	.20	.41**	.49**
16. Intrinsic motivation	-.04	.02	.17	.09	.14	.07	.89**	.05	.01
17. Satisfaction	.34**	-.53**	-.10	.38**	.45**	.21	.03	.51**	.37**
18. Performance	.51**	-.64**	.09	.55**	.57**	.28*	.08	.55**	.94**
19. Learning	.02	-.23**	.06	.06	.14	.02	-.05	.06	.35**
Block 1 Mean (SD)									
EM/Signal	6.26 (3.28)	39.00 (14.24)	179.17 (65.99)	54.68 (21.67)	27.74 (7.77)	6.53 (1.65)	28.53 (9.05)	5.42 (2.25)	83.63 (19.50)
EM/Diagnostic	6.47 (2.84)	29.16 (15.14)	159.41 71.26)	57.58 (15.43)	28.68 (7.70)	7.11 (2.13)	27.16 (5.60)	5.84 (1.80)	96.63 (16.43)
EA/Signal	7.00 (3.62)	35.16 (13.24)	215.34 (71.70)	55.37 (17.14)	27.37 (8.21)	6.47 (1.81)	29.32 (6.32)	5.32 (1.64)	95.33 (20.57)
EA/Diagnostic	8.78 (2.56)	34.72 (12.37)	182.36 (41.48)	62.00 (13.11)	32.83 (3.62)	7.50 (1.38)	29.06 (5.67)	6.00 (1.72)	97.47 (11.75)

Table 7 - 1 (continued).

Block 2	10. Analytic strategy	11. Exploration	12. Depth of processing	13. Outcome self-efficacy	14. Process self-efficacy	15. Self-set goals	16. Intrinsic Motivation	17. Satisfaction	18. Learning	19. Performance
10. Analytic strategy	*									
11. Exploration	-.22	*								
12. Depth of processing	.10	.39**	*							
13. Outcome self-efficacy	.24*	-.62**	-.28*	*						
14. Process self-efficacy	.20	-.59**	-.29*	.75**	*					
15. Self-set goal	.21	-.37**	-.36**	.54**	.44**	*				
16. Intrinsic motivation	.17	.04	.15	.08	.23*	.09	*			
17. Satisfaction	.19	-.59**	-.33**	.56**	.60**	.42**	.04	*		
18. Learning	.12	-.32**	-.07	.10	.23*	.21	-.15	.08	*	
19. Performance	.41**	-.72**	-.29*	.71**	.61**	.50**	.05	.50**	.36**	*
Block 2 Mean (SD)										
EM/ Signal Error	8.90 (3.23)	41.32 (19.51)	75.28 (24.09)	51.74 (23.51)	29.16 (9.06)	6.58 (1.77)	27.16 (9.89)	5.00 (2.00)	14.00 (2.73)	86.08 (28.43)
EM/ Diagnostic	9.05 (4.92)	27.52 (22.60)	60.61 (18.07)	61.74 (19.13)	30.63 (7.73)	7.32 (2.14)	25.58 (6.12)	6.63 (1.57)	15.37 (2.29)	103.79 (24.08)
EA/ signal error	11.16 (4.43)	31.53 (14.87)	81.73 (25.26)	59.84 (21.61)	29.63 (8.34)	6.84 (2.95)	27.26 (6.85)	6.21 (1.87)	15.11 (2.54)	100.67 (25.60)
EA/ diagnostic	8.17 (4.25)	27.06 (15.74)	75.76 (24.23)	69.22 (13.13)	34.06 (4.67)	7.22 (2.02)	26.83 (7.77)	6.33 (1.57)	15.61 (2.53)	106.18 (12.56)

Effects of error feedback and error framing on performance and learning

Hypothesis 1, which predicted that there would be an interaction between the effects of error framing and error feedback on performance and learning, was not supported. Figure 7-1 shows the performance of participants in the four conditions. A 2x2x2 repeated measures ANOVA was conducted with block 1 and block 2 as the within-subjects factor, and with error framing and feedback type as between subjects factors. This analysis showed a significant main effect for feedback type, $F(1,71)=4.23$, $p<.05$, and improvements in performance across the two blocks by all participants, $F(1,71)=28.54$, $p<.001$. The interaction of block and feedback type approached significance, $F(1,71)=3.37$, $p=.07$. Figure 7-1 shows that the EM/signal group performed worse than the other three groups. Post-hoc comparisons revealed this result to be significant in both block 1 ($t=-2.77$, 71df, $p<.01$) and block 2 ($t=-2.79$, 71df, $p<.01$). As in Study 1, performance on block 1 and block 2 correlated with the later measure of learning ($r=.35$ and $r=.36$, $p<.01$, respectively).

The full 2x2 ANOVA model, with error framing and feedback type as between participant factors, did not reveal significant effects for error framing or feedback type on learning. Figure 7-2, which shows performance on the declarative knowledge test for each group, suggests that learning in the EM/signal error group was significantly lower than for the other three groups and this difference was significant ($t=-2.05$, 73df, $p<.05$).

Figure 7 - 1: Performance

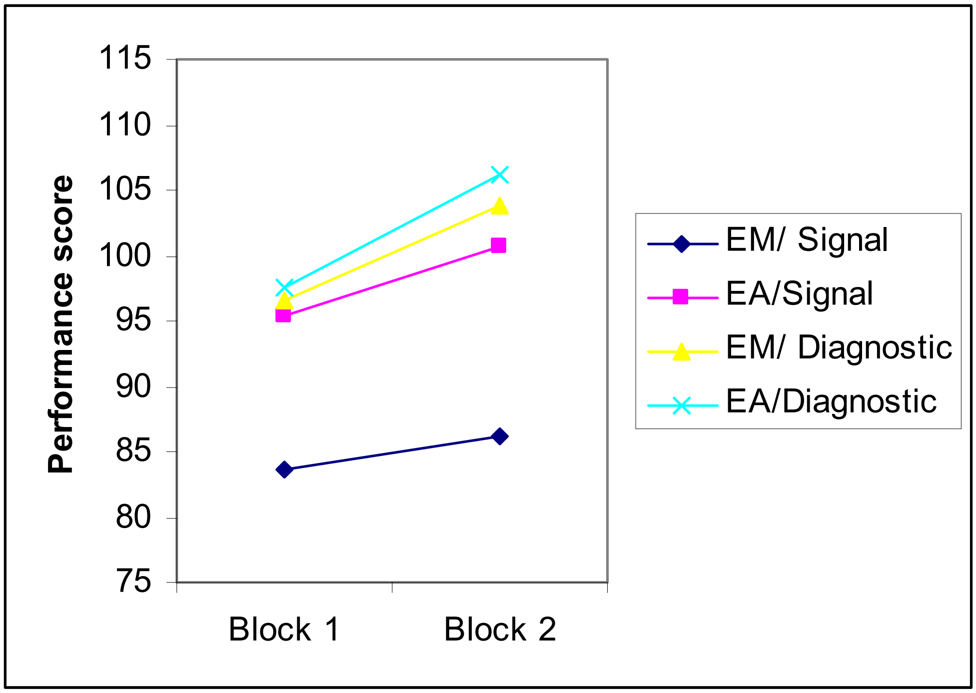
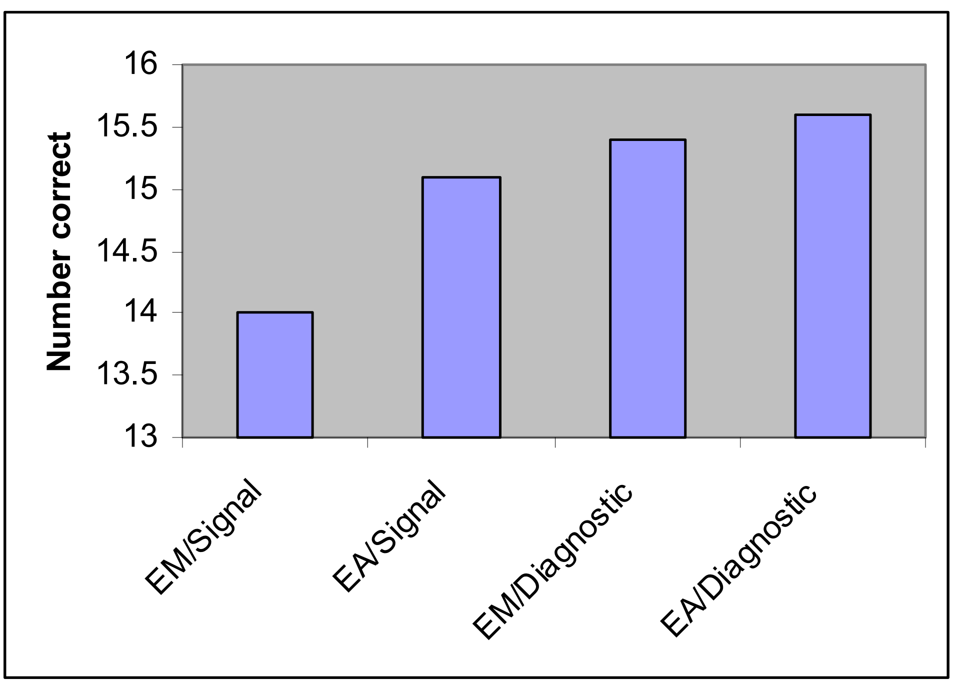


Figure 7 - 2: Number of quiz items correct



Effects of error feedback and error framing on cognitive processes

Hypothesis 2 predicted an interaction between the effects of error feedback and error framing on strategy, exploration and depth of processing. This hypothesis was partially supported, as outlined below.

Figure 7-3 shows the mean analytic strategy scores for each of the four groups. Repeated measures ANOVA showed a significant three-way interaction between block, feedback type and error framing, $F(1,71)=4.63$, $p<.05$. Both EM groups increased their use of analytic strategies over time, as did the EA/signal error group ($t=3.84$, 37df and $t=3.36$, 18df, $p<.05$). However the EA/diagnostic group showed no significant change in their use of analytic strategies over time. There was also a significant interaction between trial block and feedback type, $F(1,71)=4.84$, $p<.05$, plus a significant main effect for error framing, $F(1,71)=4.49$, $p<.05$, in block 1. However this latter effect was the opposite of what was expected. Post-hoc testing confirmed that error management instructions were associated with significantly lower use of effective analytic strategies than error avoidance instructions ($t=-2.07$, 73df, $p<.05$), but only in block 1.

Although overall there was a significant positive correlation between use of analytic strategy and performance (shown in Table 7-1), it is instructive to analyze this relationship separately for each of the four groups. Use of analytic strategy was significantly correlated with task performance for both of the EM groups and for the EA/signal error group ($r=.73$, $r=.63$, $r=.63$; $p<.05$ in all cases). However for the EA/diagnostic feedback group (which

Figure 7 - 3: Analytic strategies

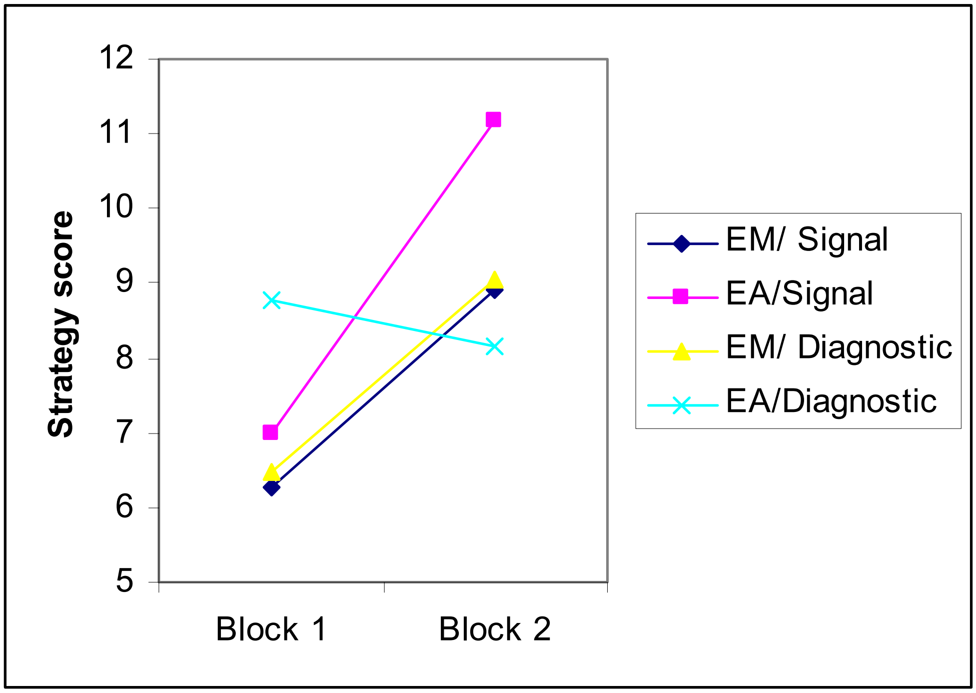
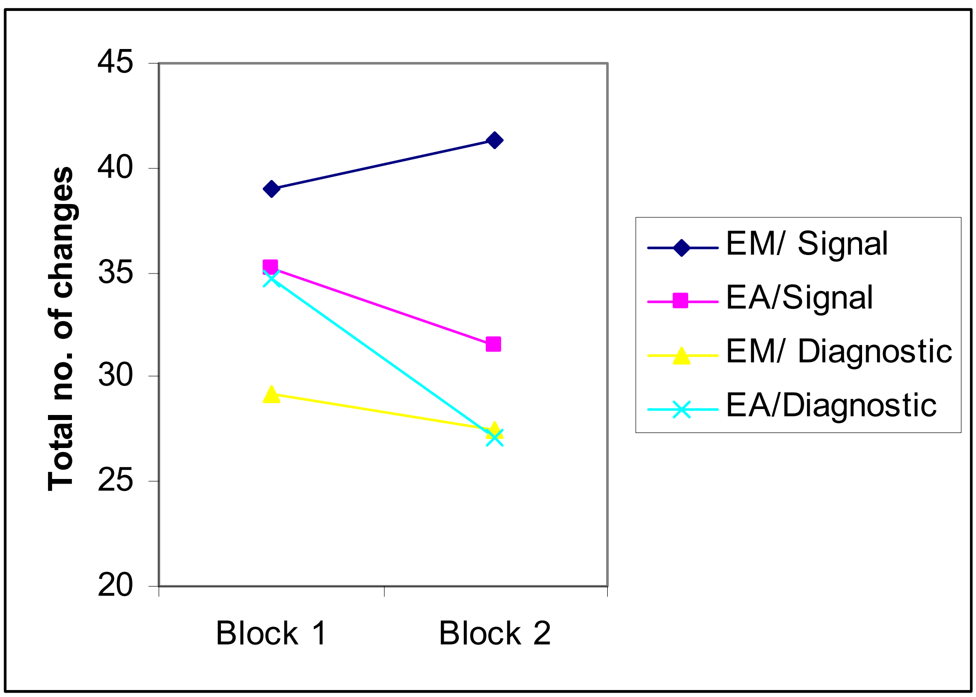


Figure 7 - 4: Exploration



demonstrated the best performance over all) there was no significant correlation between use of effective analytic strategies and performance (r=.04, p>.05).

The ANOVA for exploration revealed a significant interaction between trial block and error framing, $F(1,71)=4.32$, $p<.05$, with the EM/signal error group increasing exploration over time and showing more exploration than the other groups in block 2 (t=2.59, 73df, p<.05). In block 1 there were no significant effects for either feedback type or error framing on exploration (see Figure 7-4). In Block 2 a different pattern emerged, indicated by the significant main effect for feedback type, $F(1,71)=4.58$, $p<.05$. Signal error participants overall did more exploration than diagnostic feedback participants (t=2.06, 73df, p<.05).

Over both blocks combined, exploration was negatively correlated with task performance (r=-.71, p<.001). When each group was examined separately it was found that the negative correlation was significant and strong for both EM groups and the EA/signal error group (r=-.70, r=-.80, r=-.77 respectively, p<.05) but not for the EA/diagnostic feedback group (r=-.28, n.s.). Thus, the declining level of exploration over time by participants in the EA/diagnostic group that is evident in Figure 7-4 was not related to their level of performance. This suggests that with the additional guidance provided by the diagnostic feedback, the group developed effective approaches to the task early on and continued to apply these approaches without further exploration or analysis.

With regard to depth of processing, repeated measures ANOVA revealed significant main effects for block $F(1,71)=306.35$, $p<.01$, for feedback type $F(1,71)=4.02$, $p=.05$ and for error framing $F(1,71)=4.86$, $p<.05$. Error avoidance participants showed greater depth of processing than EM participants in both blocks, and signal error feedback was associated with greater depth of processing than diagnostic feedback (see Figure 7-5). Overall, depth of processing declined between block 1 and block 2.

Effects of error feedback and error framing on self-regulatory processes

Hypothesis 3 predicted that there would be an interaction between the effects of error feedback and error framing instructions on self-efficacy, self-set goals, intrinsic motivation and affect (satisfaction). This was partially supported as outlined below.

With the inclusion of error framing, differences in self-efficacy were evident in the outcome self-efficacy beliefs but not in the process self-efficacy beliefs, which is the reverse of the effects observed for the two sets of efficacy beliefs in Study 1.

Repeated measures ANOVA revealed two significant interactions for outcome self-efficacy. The first was between assessment phase and error feedback, $F(1,71)=4.44$, $p<.05$, and the second was between assessment phase and error framing, $F(1,71)=5.03$, $p<.05$. There was also a main effect for assessment phase, $F(1,71)=7.61$, $p<.01$.

Post-hoc comparisons showed that following the first block of trials the four groups did not differ significantly in their outcome self-efficacy. The changes in outcome self-efficacy between blocks 1 and 2, shown as the interactions in Figure 7-6, produced a main effect for feedback type in block 2, $F(1,71)=4.48$, $p<.05$. Both of the groups receiving diagnostic feedback had significantly stronger self-efficacy in the second assessment phase than in the first assessment phase ($t=2.13$, 18df for EM/diagnostic and $t=2.76$, 17df for EA/diagnostic, $p<.05$). The group receiving EA/signal error feedback showed no significant change in self-efficacy over time but the self-efficacy of the EM/signal error group declined the longer

Figure 7 - 5: Depth of processing

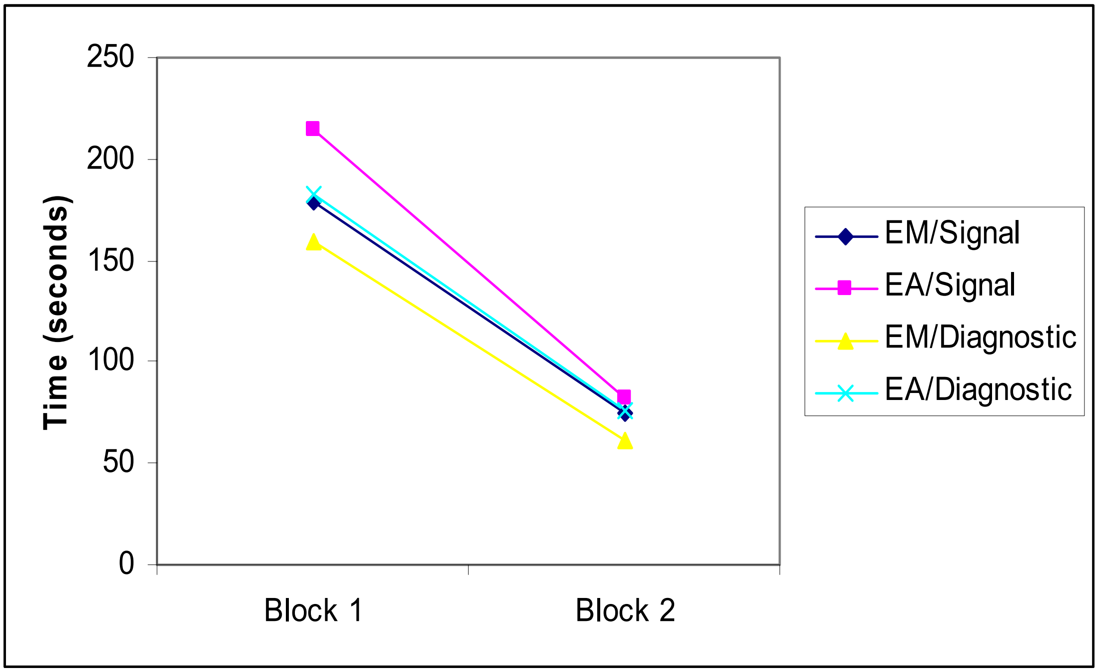
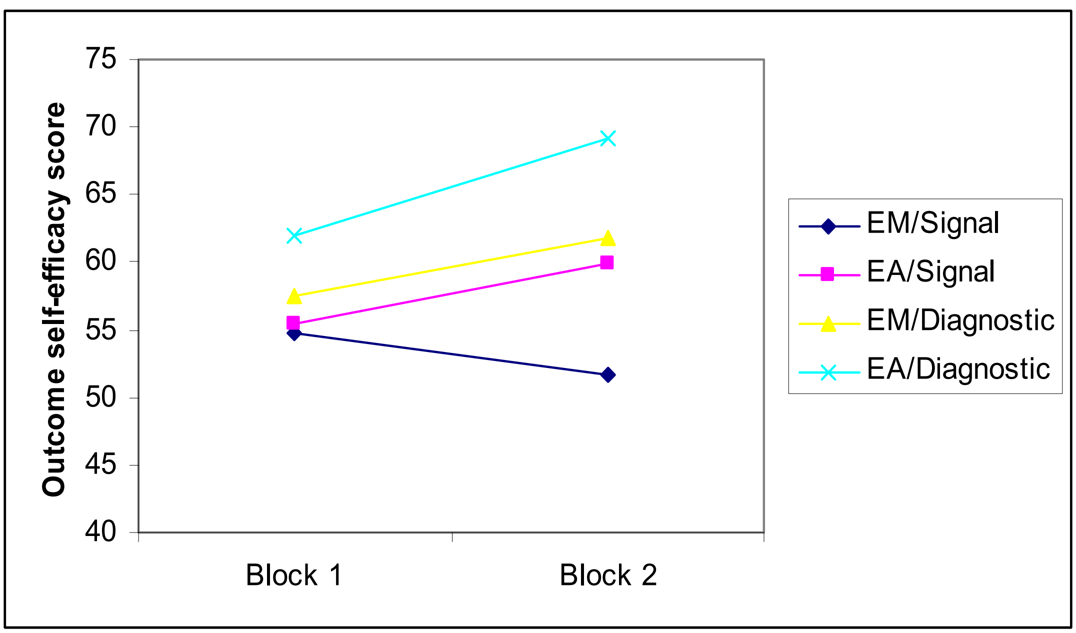


Figure 7 - 6: Outcome self-efficacy



they worked on the task, resulting in lower self-efficacy scores at the end of the study for this group than for any of the other groups (t=2.23, 73df, p<.05).

There were no significant main or interaction effects for error feedback or error framing on process self-efficacy in either assessment phase. Repeated measures ANOVA showed that all participants became more confident in their decision making abilities the longer they worked on the simulation, $F(1,71)=11.67$, $p<.05$.

In the first assessment phase there was a significant main effect of error feedback type on self-set goals, $F(1,71)=3.89$, $p=.05$. Participants in the two diagnostic feedback groups set themselves higher goals than did those in the two signal error feedback groups (t=1.97, 73df, p=.05; see Figure 7-7). Participants made minor changes in their goal levels between the first and second phases and there were no significant effects by the end of block 2. Error framing had no effect on levels of self-set goals.

There were no significant main or interaction effects of error feedback or error framing on intrinsic motivation in either assessment phase. Repeated measures ANOVA showed that intrinsic motivation tended to decrease between assessment phases 1 and 2, $F(1,71)=19.21$, $p<.05$, see Figure 7-8. This may have been a result of fatigue but the lack of main or interaction effects indicates that neither the extra information provided by diagnostic feedback nor the EM/EA instructions affected intrinsic motivation.

In the first assessment phase there were no significant main effects for error feedback or error framing on satisfaction. Repeated measures ANOVA revealed a significant three-way

Figure 7 -7: Self-set goals

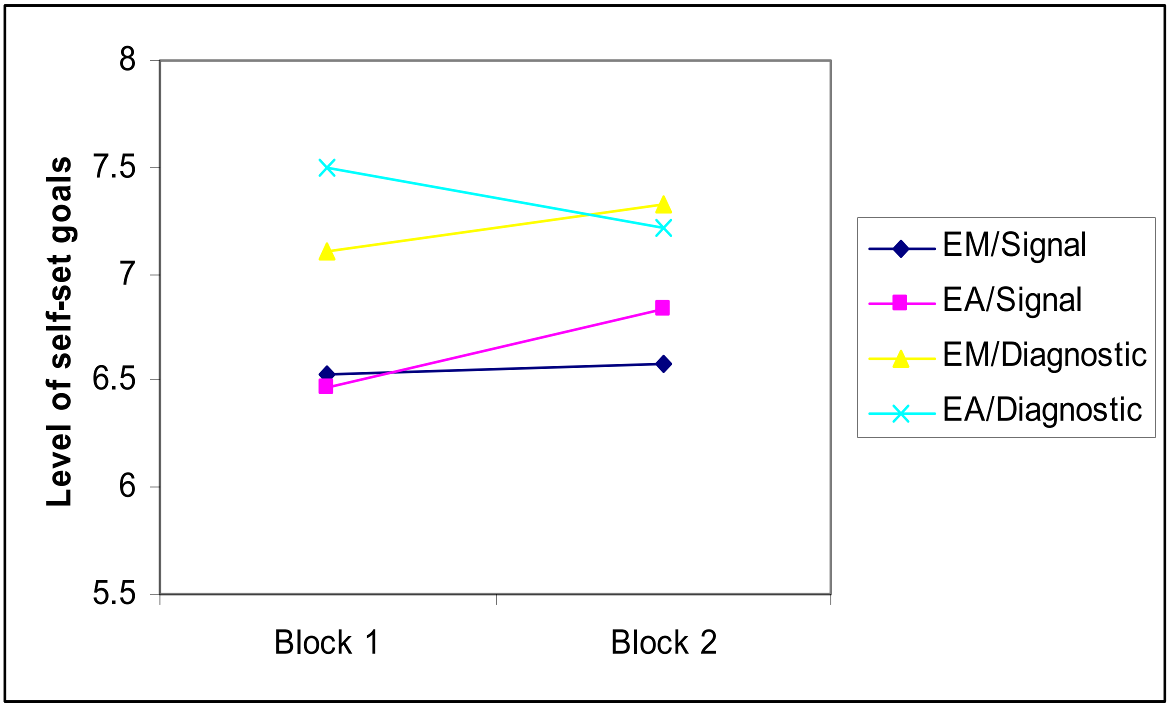
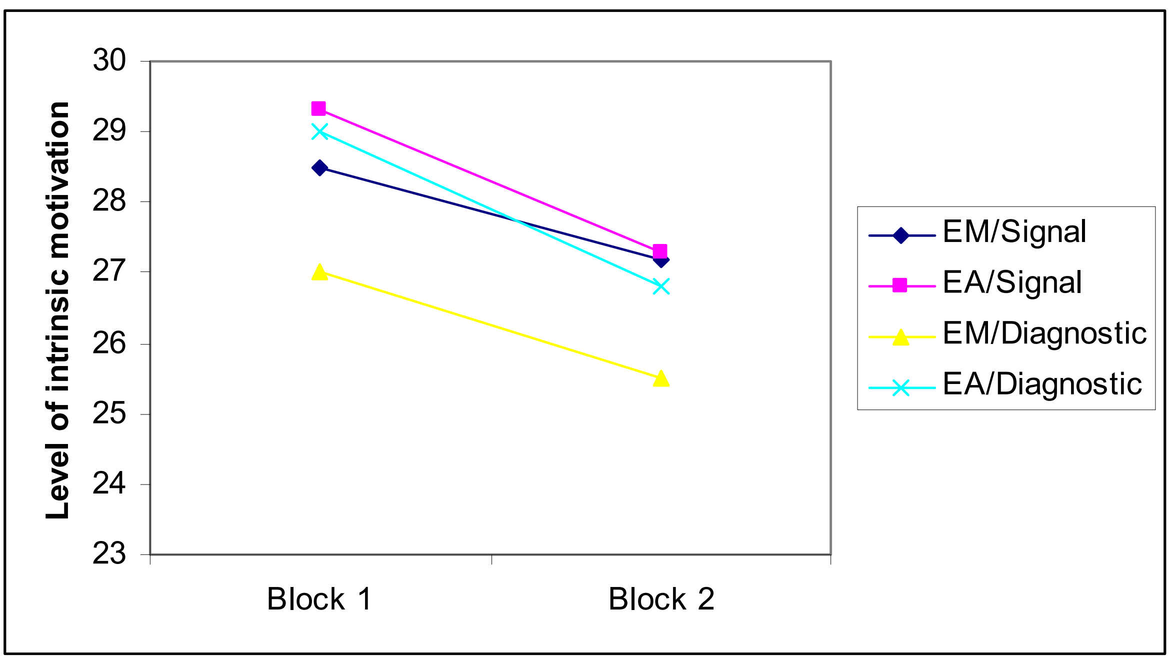


Figure 7 - 8: Intrinsic motivation



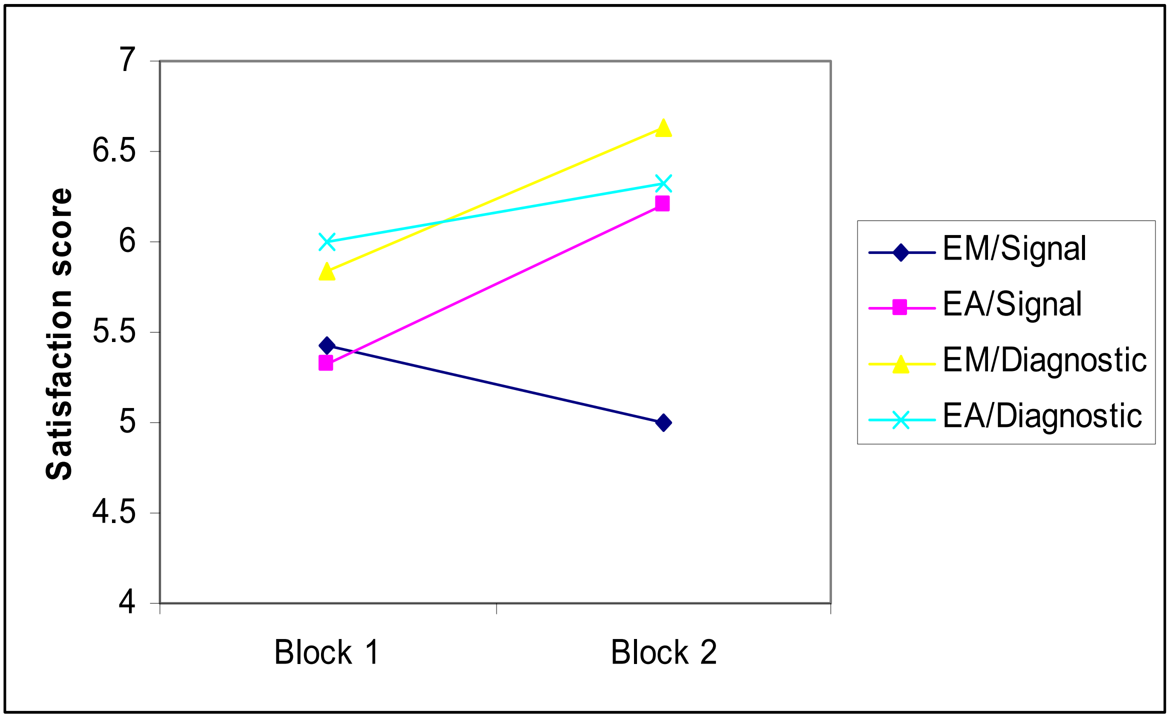
interaction between assessment phase, error feedback and error framing, $F(1,71)=4.59$, $p<.05$. Figure 7-9 shows that, over time, the satisfaction levels of the EM/diagnostic feedback and EA/signal error feedback groups increased ($t=2.33$, 18df, $p<.05$ and $t=2.39$, 18df, $p<.05$, respectively). The drop in satisfaction between the first and second assessment phase for the EM/signal error group was not significant but this group did have significantly lower satisfaction than the other three groups at the second assessment phase ($t=3.0$, 73df, $p<.05$).

Mediation analyses

It was hypothesized that cognitive and self-regulatory processes would mediate the impacts of error feedback and error framing on performance and learning. Prior analysis (reported above) identified that there was no significant effect of error framing on performance, and no effect of error framing or error feedback on learning. Mediators were therefore tested for the relationship between error feedback and performance.

In all models, the introduction of the single mediator reduced the impact of the feedback type on performance from significance to non-significance. Exploration and analytic strategy each fully mediated the impacts of diagnostic feedback on performance. Tests of the individual self-regulatory mediators showed that self-efficacy, self-satisfaction and self-set goals mediated the effect of feedback type on performance. Tests of significance using the Sobel test did not support inferences that the changes in beta were significant for individual models 1 to 6. With all possible mediation variables included in the regression (model 7), the impacts of feedback type on performance were fully mediated. In the full model, the significant mediational pathways, after controlling for the effects of all other

Figure 7 - 9: Satisfaction with performance



mediators were exploration (beta=-.34), strategy (beta=.22), self-efficacy (beta=.19) and satisfaction (beta=.20). The R^2 change following the introduction of the mediators indicates that, in addition to the mediation effects, the mediator variables had direct additive effects on performance.

Table 7-2: Mediation of cognitive and self-regulatory processes on the relationship between error feedback and performance.

Dependent variable	Independent variables	Beta	Change in beta[7]	Sobel test[8]	R^2 change	df
Model 1						
Performance	Feedback type	.24*			.06	1,73
Model 2						
Performance	Feedback type	.12	50%	1.59	.42	2,72
	Exploration	-.61***				
Model 3						
Performance	Feedback type	.17	29%	1.27	.29	2,72
	Strategy	.49***				
Model 4						
Performance	Feedback type	.17	29%	1.17	.33	2,72
	Self-efficacy	.53***				
Model 5						
Performance	Feedback type	.16	33%	1.25	.33	2,72
	Satisfaction	.52***				
Model 6						
Performance	Feedback type	.19	21%	1.44	.11	2,72
	Goals	.24*				
Model 7						
Performance	Feedback type	.09	63%		.57	6,68
	Exploration	-.34**				
	Strategy	.22*				
	Self-efficacy	.19*				
	Satisfaction	.20*				
	Goals	-.03				

[7] Percentage attenuation of the feedback type β following the introduction of the mediator variables.

[8] Tests whether the indirect effect of the IV on the DV via the mediator is significantly different from zero. The test statistics reported here did not reach conventional levels of significance. There is no straightforward way to test for significance in the full model (Model 7).

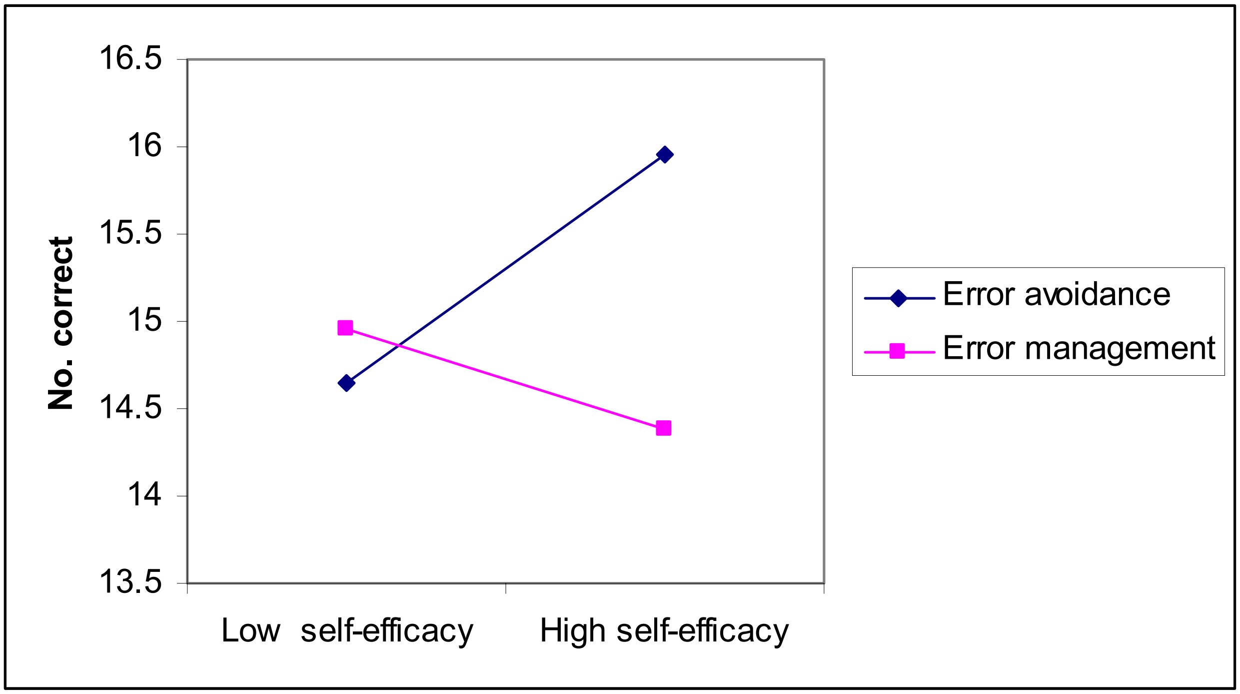
Interaction effects

For the analysis of interaction effects as predicted by Hypotheses 6 and 7, error feedback was coded so that 0=signal error feedback and 1=diagnostic feedback. Error framing was dummy coded so that 0=error avoidance framing and 1=error management framing. Process self-efficacy and outcome self-efficacy and strategy were each centered around their means to remove scale effects in the interpretation of the *b* (Aitken & O'Driscoll, 1998).

There was support for the effects of the outcome self-efficacy x error framing interaction on learning($b=-6.80E-02$, beta = -.351, $p<.05$), and the process self-efficacy x error framing interaction on learning ($b=-.238$, beta=-.51, $p<.01$). All other hypothesized interactions were not supported.

To facilitate reporting of interaction effects, outcome and process self-efficacy were combined into a single measure. The combined self-efficacy measure for block 1 had a good reliability (alpha=.85). Figure 7-10 shows that participants with low self-efficacy showed relatively low levels of learning under both error avoidance and error management framing. For participants with high self-efficacy, error avoidance framing resulted in high levels of learning but error management instructions resulted in low levels of learning. The role of self-efficacy in the error framing process clearly requires further investigation.

Figure 7-10: Interaction effects of self-efficacy and error framing on learning



Discussion

As in Study 1, participants who received diagnostic feedback performed better than those receiving signal error feedback. Diagnostic feedback also produced less exploration, better self-efficacy, higher self-set goals and greater self-satisfaction than did signal error feedback, which mediated the impacts of feedback on performance. Study 2 therefore confirmed that the nature of the feedback provided about errors affected the cognitive and self-regulatory processes that influenced performance on the task. However as with Study 1, this did not translate into better conscious recall of the decision rules, with one exception which will be discussed later.

The effects of error framing were unexpected. Overall, error avoidance framing resulted in better strategy and better depth of processing of information than the more positive error management framing. The framing of errors interacted with the nature of error feedback: the combination of positive error framing and signal error feedback resulted in worse performance and learning than any other combination of error feedback and error framing.

The effects of feedback on performance were fully mediated by cognitive and self-regulatory processes. The main mediation pathways were exploration, strategy, self-efficacy, satisfaction and self-set goals, although goals were not significant when all other mediators were included in the full model. As in the first study, exploration had a negative effect on performance whereas analytic strategy, self-efficacy, self-set goals and satisfaction were positive mediators. Good task performance required participants to use effective, systematic problem-solving approaches rather than exploration. Rather than boosting the effectiveness of signal error feedback, positive error framing magnified the deleterious effects of such feedback by encouraging exploration rather than strategic identification of decision rules.

Error avoidance instructions resulted in more learning for participants with high self-efficacy but less learning for those with low self-efficacy. However when error management instructions were provided, participants with low self-efficacy learned more than those with high self-efficacy. For those who lacked confidence with the task it was helpful to frame errors positively but for confident participants it was of more value to emphasize correct performance instead of learning from errors.

Overall, the results of Study 2 have supported the advantages of diagnostic feedback for performance over signal error feedback found in Study 1, and have also shown that framing errors positively does not necessarily facilitate task performance and learning. The implications of the results from Studies 1 and 2 for future research and for practice are discussed in the next chapter.

Chapter 8: General Discussion

In both studies, participants receiving diagnostic feedback outperformed those who received signal error feedback or outcome feedback, but feedback type did not affect participants' conscious understanding of the task. The hypothesized benefits of diagnostic feedback were based on the argument that diagnostic feedback would provide better support for strategic learning approaches by helping learners identify and systematically test decision rules (Earley et al., 1990; Wood, 1997; Wood & Locke, 1990). Results of both studies supported this argument, as participants receiving diagnostic feedback used effective analytic strategies more than participants who received signal error and outcome feedback. The beneficial effects of diagnostic feedback for performance were also mediated through reduced unsystematic exploration, stronger self-efficacy, greater satisfaction and higher self-set goals in the full model.

The hypotheses that signal error feedback would guide learning by alerting learners to the errors they had made and by prompting deeper processing of information were not supported. Signal error feedback prompted participants to use high levels of unsystematic exploration and poor analytic strategies. Participants were unable to use the information uncovered during unsystematic exploration to identify more effective strategies, whereas diagnostic feedback assisted learners to identify and use effective decision rules.

Unsystematic exploration had negative effects on performance on the experimental task. While it has often been argued that exploration can help learners uncover aspects of the problem space they would not otherwise have encountered, exploration is only beneficial when learners can interpret the results of their actions and build valid representations of the decision rules. (Carlson et al., 1992; Davis & Wiedenbeck, 1998; Deci & Ryan, 1980; Dormann & Frese, 1994; Frese, 1995; Frese et al., 1988; Frese & Altmann, 1989; Frese & Zapf, 1994; Kamouri et al., 1986; Nordstrom et al., 1998; Schmalhofer et al., 1990). In the present research the complexity of the task and the number of decision rules meant that participants needed diagnostic feedback to be able to identify and correct their errors. Without diagnostic feedback, unstructured exploration proved detrimental to task performance. Instead of unstructured exploration, a better approach to learning the task was to systematically construct hypotheses about how factors affect outcomes and then test those hypotheses (Debowski et al., 2001; Frese, 1995; Wood & Bandura, 1989; Wood et al., 1990; Wood et al., 2000). Diagnostic feedback guided participants to use good strategies by providing information that allowed hypotheses to be set up and tested. Outcome feedback and signal error feedback were deficient in relevant information and did not help with hypothesis development and testing. In the absence of informative feedback, participants were unable to use the information uncovered during unsystematic exploration to identify more effective strategies.

Diagnostic feedback also helped learners to build good self-efficacy for the task, to feel satisfied with their task performance, and to set themselves higher goals. The impoverished information provided by signal error and outcome feedback was especially harmful to the performance of participants with low self-efficacy for the task whereas those with high self-efficacy did relatively well in all feedback conditions. Appropriate levels of feedback information are therefore important for all learners, but especially for those who lack confidence in learning a new task.

The hypothesized benefits of positive error framing were based on the arguments that, by reducing the anxiety associated with errors and alerting learners to the information to be extracted from errors, positive error framing would encourage trainees to learn from their errors (Dormann & Frese, 1994; Frese, 1995; Frese et al., 1988; Frese & Altmann, 1989; Frese & Zapf, 1994; Ivancic & Hesketh, 1995). In the present research however, it was error avoidance framing rather than error management framing that led to better performance. The effects of error framing were mediated by better use of analytic strategies, less exploration, better self-efficacy, more self-satisfaction and higher self-set goals.

The effectiveness of error framing is affected by the nature of the feedback provided about the task. If error feedback cannot be easily interpreted, errors become a 'bother' rather than an impetus to learn (Frese & Altmann, 1989). Positive error framing can prompt unsystematic exploration (Dormann & Frese, 1994) but if feedback is inadequate then learners are unable to use the information uncovered during exploration to identify more effective strategies for problem-solving. In the present research, the combination of positive error framing and signal error feedback led to particularly high levels of exploration and also to poor performance, declining outcome self-efficacy and declining satisfaction. In the absence of good error feedback error management framing can prompt unsystematic exploration rather than the use of good analytic strategies, and can result in slower and less effective learning and poorer performance.

Without error framing, diagnostic feedback in Study 1 gave learners confidence in their ability to manage the relevant task processes and make correct decisions but did not increase confidence in their ability to achieve good outcomes. However the error framing in Study 2 shifted participants' focus from task processes to task outcomes. This is not surprising given that the error framing heuristics explicitly linked errors to performance and learning outcomes. The heuristics therefore made outcomes, as well as errors, salient. This effect requires further investigation. It is unclear whether the effects of error management heuristics may arise from shifting learners' attention away from task processes towards task outcomes as well as by increasing the salience of errors themselves.

Error framing interacted with participants' self-efficacy to affect learning. Participants with low self-efficacy learned more about the task when given error management instructions instead of error avoidance instructions, but those with high self-efficacy learned more when instructed to avoid errors than when instructed to learn from errors. When learners have low efficacy it may be helpful to provide positive error framing in order to mitigate the negative affective reactions that can arise from errors (Frese & Altmann, 1989; Ivancic & Hesketh, 1995). But for learners with more confidence it was more helpful to emphasize error avoidance and good analytic strategies rather than learning from errors. While positive error framing may be intuitively appealing it has potential costs. If error management framing encourages ineffective exploration, the resulting frustration can have negative motivational effects such as lower self-efficacy and greater dissatisfaction. Feedback has to help learners identify and correct their errors and get out of error situations (Dormann & Frese, 1994; Frese, 1995; Frese & Altmann, 1989; Frese et al., 1991; Nordstrom et al., 1998). When a task is complex and feedback is unclear it is better not to encourage learners to make errors unless diagnostic feedback is available.

Research implications

Error management framing has been shown to be effective with word-processing or statistical analysis tasks in which the menu based structures provide feedback on the relationship of strategy to outcomes, but less effective in tasks such as CD-ROM searching in which only outcome feedback is generally available. The interactive effects of error framing and error feedback need further investigation, particularly in terms of how task-related feedback supports either unsystematic exploration or the systematic use of analytic strategies.

Investigation is needed into how tasks differ in the degree to which learners' decision options are constrained, the extent to which exploration is a useful strategy for learning the task, and how these differences affect the value of error feedback and error framing. It is also important to clarify how learners' requirements change as they gain experience with the task. Novices may require feedback that supports the use of effective analytic strategies, whereas more advanced learners may benefit from feedback that emphasizes and guides exploration.

Little is as yet known about interactions between the type of error feedback and the type of errors. The effectiveness of different forms of error feedback may be affected by the nature of the error. Signal error feedback may be best for skill-based errors where knowledge of rules and principles is not required for error correction. Diagnostic feedback may be most useful for errors that are due to inadequate knowledge or poor application of rules. Further research should consider the different types of errors and investigate which forms of feedback best help trainees to learn from each.

Cognitive and self-regulatory processes need further examination, as they relate to error framing and error feedback. The effectiveness of different forms of error feedback may depend on learner ability as well as motivation and other variables. The effectiveness of error framing is affected by learner self-efficacy. Further research is required to identify the processes that mediate and interact with error feedback and error framing.

Implications for practice

Errors in training can help learners to understand how errors arise, how to deal with errors and how to prevent them (Baldwin & Ford, 1988; Frese & van Dyck, 1996; Frese, 1995; Frese & Altmann, 1989; Frese & Zapf, 1994; Ivancic & Hesketh, 1995; Needham & Begg, 1991; Pruemper et al., 1992; Schmidt & Bjork, 1992). But for error training to be valuable, appropriate error feedback must be provided. Good error feedback helps learners to understand what the error was, how it arose, what must be done to prevent its recurrence and how to escape the situation which the error has created (Frese, 1995; Frese & Altmann, 1989).

Error diagnosis is a problem for novices who often lack the necessary knowledge to interpret error feedback (Frese & Altmann, 1989). Diagnostic feedback not only helps learners to diagnose their errors, but also helps learners to use effective strategies for learning and understanding a complex task. Many existing software packages for example do not provide diagnostic feedback on errors, only signal error feedback (at best), and many people must learn to use software independently and without task-related training. It may be helpful to train novice computer users in effective analytic strategies as well as in the interpretation of task-specific feedback. Effective strategies have been identified for different tasks e.g. the use of 'help' facilities for menu-based software, and the use of thesauruses and dictionaries for electronic searching. More task-specific strategies need to be identified and tested and methods developed for training users to employ them effectively.

Positive error framing should be used with caution as it tends to prompt ineffective unsystematic exploration rather than systematic hypothesis-testing. If the task itself does not provide good diagnostic feedback, then structured learning approaches are preferable to trial-and-error learning. Once learners have developed core competencies and self-efficacy for the task it is more helpful to emphasize correct performance and good learning strategies than to stress learning from errors. Exceptions may occur when a task is highly structured and provides immediate diagnostic feedback, or when learners lack confidence for the task. Under these conditions positive error framing can help learners to focus on the information that an error provides and to learn strategies for dealing with error situations. However when tasks are unstructured, feedback is ambiguous and learners are relatively confident, learners will benefit more from instructions which emphasis correct performance than from an emphasis on making errors.

The generalizability of results reported in Study 1 and Study 2 is yet to be established. Although the present task was unrelated to participants' studies or work, the results are consistent with other research into enactive exploration (combining error framing and exploratory learning) that used an ecologically valid electronic search task (Debowski et al., 2001). If supported, these findings suggest that error framing, while attractive in principle, may have hidden costs. If it encourages exploration and experimentation this may result in better learning; however if learners become indifferent to errors, or persist in exploring rather than applying effective analytic strategies this may be detrimental to performance. Error avoidance instructions may have positive effects by encouraging learners to pay attention to available feedback information. Further investigation is needed into the mechanisms that underlie the relative effectiveness of positive and negative error framing.

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