Breaking the Safety Barrier

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Engineering New Paradigms
in Safety Design

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Abstract

Occupational health and safety legislation in Australia and internationally is based on the safe place concept and the hierarchy of control. A safe place is best achieved at the design stage and consequently the education of engineers in safety has been a priority. There have been notable efforts at the integration of safety with engineering studies, and this should be an ongoing objective, however extensive integration is likely to be difficult at least in the short term.

The challenge was to develop a supplemental, innovative way to improve the ability of engineers to develop safe place solutions. The hypothesis was that training in creative thinking would achieve this aim. The hierarchy of control methodology shares a strong relationship with creative thinking. Safe place thinking challenges assumptions in the same way that creative thinking seeks to escape dominant paradigms. For this reason creative thinking seems a natural aid to the safe place approach.

This study tested the effect on safety design of a creative thinking program; de Bono's six thinking hats method. Given a recognition that groups other than engineers impact on workplace design, a range of subjects were included; engineering students, technology students, industry safety advisers, and government safety advisers.

In response to safety case studies, subjects were required to generate solutions and to prioritize potential solutions. Subjects worked on a range of problems, some individually and some in teams of three. Results show that training in creative thinking improved the generation of solutions to safety problems. As the number of solutions increased, the average quality of ideas was maintained, therefore the increased number of solutions was accompanied by a similar increase in good quality safe place solutions. The results also showed in some instances the training improved the prioritization of solutions according to the safe place methodology. The effects were of a similar magnitude for individuals and teams.

Creative thinking training was shown to be a useful way to enhance the generation of safe place solutions to safety problems. Given that creative thinking skills can theoretically be applied to any area of problem solving, the enhancement of these skills are likely to yield wider benefits. Furthermore the enhancement of creative thinking accords well with the current industrial mandates for improved innovation.

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Declaration

This thesis is less than 100,000 words in length, exclusive of tables, maps, bibliographies, appendices and footnotes. Except where explicit reference is made in the text of the thesis, this thesis contains no material published elsewhere[1] or extracted in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma. No other person's work has been relied upon or used without due acknowledgment in the main text and bibliography of the thesis.

John Culvenor

Professor Dennis Else (Supervisor)

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1 In the course of undertaking this work I have given a number of conference presentations and have a number of articles in the publication process. These are listed in the bibliography.

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Chapter One

Introduction

1. Introduction

1.1 The Problem

Each year in Australia there are approximately 650,000 workplace injuries (Industry Commission 1995). Five-hundred of these injuries result in death and 160,000 involve greater than five days lost time (Worksafe Australia 1995). In financial terms the workers' compensation bill is approximately $4,800M per annum (ABS 1995; 1993-94). When allowing for the substantial indirect costs and also the many unreported injuries and diseases, estimates of the total cost are much greater. Worksafe Australia (1994) suggested the figure could be as high as $37,000M (1992-93), while the Industry Commission (1995) estimated the total cost to be around $20,000M (1992-93).

To place these figures in context, Australian Gross Domestic Product and the Gross Farm Product were estimated at $430,000M and $12,000M respectively (ABS 1996; 1992-93). The health and safety problem (based on $20,000M) can therefore be considered to be of the order of five percent of GDP and greater in magnitude than the Gross Farm Product.

The sponsor of this research, the *National Occupational Health and Safety Commission* (*NOHSC* or *Worksafe Australia*), directed the research toward the problem of *mechanical equipment injuries*. The National Commission estimated that mechanical equipment featured in over 80% of all work related fatalities and contributed to 28% of compensible injuries (NOHSC 1990c). Mechanical equipment is therefore involved in 400 workplace deaths and probably contributes $5600M (based on $20,000M total) annually to the cost of workplace injuries. Behind the economic losses obviously exists a considerable burden of pain and suffering, especially considering the high involvement of mechanical equipment features in workplace deaths. While small in number compared to the total number of injuries, workplace fatalities obviously have a profound impact. In summary, it is clear mechanical equipment injury contributes a sizeable legacy of pain, suffering and economic loss and is an area where great improvement should be sought.

In the *National Strategy for the Prevention of Mechanical Equipment Injury,* the NOHSC (1990c), outlined their approach to address this problem. They highlighted research priorities in the areas of legislation, education, management, and engineering and technology interventions. The research here concentrated on engineering and technology interventions; about which the National Commission said;

> *Research is needed on the development, implementation and evaluation of interventions which:*
> *facilitate research and development of new approaches to engineering/technology safety measures and their incorporation into the design of equipment;*
> *stimulate greater application of known engineering/technology safety measures in the design or redesign of mechanical equipment, work processes, etc; and*
> *increase application of known engineering/technology safety measures already in the workplace. (NOHSC 1990c, p. 14.)*

These research needs were distilled to two main themes;

1. the development of new safety measures; and
2. the application of existing safety measures.

The research described in this thesis focuses on these two themes, but is not limited to mechanical equipment injury. The reasoning is that the methodologies for prevention of mechanical equipment injury apply to a wide array of problems. In relation to this point, the National Commission commented that '*...many of the preventative measures proposed in this strategy will also be applicable to other types of injury'* (NOHSC 1990c, p. 3).

Injury prevention measures should be aligned to the *safe place* model that underpins current legislation in Australia and internationally, however efforts in the past have often been preoccupied with behavioural strategies, or a *safe person* model. The safe person way of thinking owes its origins to the unsafe act and unsafe condition model of accident causation. Accident scenarios invariably implicated people and thus the unsafe act was seen to be the dominant cause. However, as noted by the Industry Commission (1995), encouraging safe behaviour is rarely an effective way to prevent injuries.

> *Only very limited, if any, control is possible by focussing on the behaviour of those who may be injured. (Industry Commission 1995, p. xx)*

Similarly, in the recently published standard for the *Safeguarding of Machinery*, Standards Australia highlighted the misleading attention given to the role of unsafe acts and the consequential concealment of opportunities for safe design.

> *Accidents with machines have often been attributed to 'unsafe acts', when a more thorough study would have revealed a design deficiency which did not allow for typical foreseeable human characteristics or behaviour. (Standards Australia 1996, AS4024.1, p. 12)*

The alternative to the philosophy of encouraging safe behaviour, is to design the system to minimise accidents, a course of action now referred to as *safe place* design. This way of thinking, and the now familiar hierarchy of control, is a general methodology for tackling health and safety problems. The emphasis for prevention is on employing controls that eliminate hazards or maintain control over the hazards in a passive way. Passive control implies the absence of reliance on the vigilance of people. As a consequence of the need to *design for people*, ergonomics is now an integral part of the safe place approach.

The *safe place* ideal implies a vital role for engineers. Given their influence over design, and the need for safety to be incorporated at the design stage, the education of engineers in the principles of safety has been a priority for many years. For instance the UK report known as the Robens Report said;

> *...professional engineering institutions could make their concern with the subject much more explicit by including safety and health as an item in their syllabuses and examinations (Committee on Safety and Health at Work 1972, p. 127)*

In the United States, the National Institute for Occupational Safety and Health, identified the need for occupational health and safety in engineering studies (NIOSH 1984). They recommended that engineering curricula feature required studies in occupational safety and health as well as providing elective, and specialty options.

> *All undergraduate engineering curricula should include a required course that will include instruction on the responsibilities of engineers for occupational safety and health and an awareness of occupational safety and health engineering problems and solutions. (NIOSH 1984, p. 28)*

The National Occupational Health and Safety Commission in their *National Education and Training Strategy for Occupational Health and Safety* (1993) made the integration of occupational health and safety into all undergraduate and postgraduate eduction one of its five goals. Clearly engineers are a key group to be targeted through such a strategy.

> *[Goal:] To promote the integration of quality OHS into education and training for all vocations and professions. (NOHSC 1993b, p. 6)*

The Institution of Engineers, Australia (IEAust) emphasised the responsibility of engineers for safety as a key ethical requirement. In its *Code of Ethics* (1994) the IEAust outlined nine tenets of the ethical behaviour; the *first* of which stressed the importance of safety.

> *[Tenet One:] members shall at all times place their responsibility for the welfare, health and safety of the community before their responsibility to sectional or private interests, or to other members (The Institution of Engineers, Australia 1994, p. 3)*

Since around 1980 a number of universities such as; Purdue University, and Ohio State University, in the United States (Talty 1986); Delft University of Technology in the Netherlands (Lemkowitz 1992); and the University of Ballarat here in Australia (Woolley & Viner 1980) have begun the integration of safety topics with engineering studies. Similarly in the United Kingdom the accreditation syllabus of the Institution of Chemical Engineers has since 1983 required subjects on safety (Kletz 1990b). In addition, there have been wider programs that aimed to facilitate the integration of safety and engineering education. These have included the NIOSH (USA) *Safety and Health Awareness for*

Preventative Engineering program that began in the 1980's (Talty 1995) and more recently, the National Occupational Health and Safety Commission's, *OHS for Engineers* program (NOHSC 1990d).

While the integration of safety with engineering education is important, a number of authors have commented that it has not been sufficiently widespread (NIOSH 1984; Office of Technology Assessment 1985; Talty 1986; Kavianian 1989; NIOSH 1990; Hale 1994). It has been suggested that a barrier to integration of safety is the already crowded nature of engineering curricula and the continued pressure for the inclusion of material (Office of Technology Assessment 1985; Talty 1986). While safety education for engineers should remain a priority, there appear to be obstacles, at least in the short term, to its full integration. The challenge for the work here was therefore to propose a supplemental, innovative way of improving the ability of engineers to develop safe place solutions.

The proposal is that while the importance of safety education for engineers is unquestioned, there may be an application for education in creative thinking skills; skills that apply not to safety specifically but to any area of work. This idea arose as it became apparant that the thinking needed to apply the *hierarchy of control* process shares a strong relationship with many of the principles of creative thinking. The high-order *safe place* controls direct attention toward control at source. This is challenging as it involves rethinking assumptions and re-examining hazardous work processes. Creative thinking implies a similar approach, thinking *outside the square*. The role of creative thought seems integral to the application of high-order hazard controls.

Together with a seemingly natural role in prevention, creative thinking now seems to be gaining prominence as an important industrial skill. For instance, management writers have emphasised the need for innovation (Senge 1992) while the Australian Manufacturing Council Secretariat said that *'Innovation will be the next source of substantial growth'* (AMC 1994, p. 1). The AMC predicted (Figure 1-1) that innovation represents the phase that will follow past sources of improvement such as *cost* and more recently *quality and service*. Should they be accurate, innovation will shortly be a topic of interest in Australian industry at a level equivalent to that of quality in the 1980's and early 1990's.

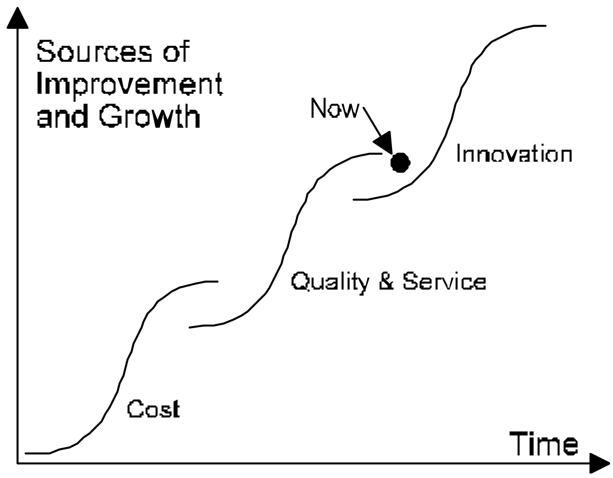


Figure 1-1 Sources of Performance Improvement and Growth
(adapted from AMC 1994)

Similarly, the review of engineering education, *Changing the Culture: Engineering education into the future*, commissioned by The Institution of Engineers Australia, the Academy of Technological Sciences and Engineering, and the Australian Council of Engineering Deans, stressed the need for creative thinking skills.

> *There is a need for the introduction into courses at an early stage of greater attention to problem solving and the encouragement of creativity and innovation - knowing when analysis stops and synthesis starts. (IEAust, ATSE & EACED 1996, p. 7)*

It seems that techniques for creative thinking therefore may accord with a current industrial need for innovation and a recognised need for these skills in engineering education.

1.2 The Problem Summary

Improved safety relies on the application of the safe place design principle. Engineers appear best positioned to achieve safe place design and so the enhancement of safety studies in engineering education has been a priority, and this focus should be maintained. However, given that the integration of safety with engineering education has been problematic, the challenge is to investigate a supplemental and innovative way to improve engineers' ability to design for safety.

1.3 Aim

To investigate an innovative way of improving the ability of engineers to design for safety.

1.4 Hypothesis

The hypothesis is that training in creative thinking methods will be an effective way to improve the ability of engineers to design for safety.

1.5 Objectives

- To establish the model of prevention that would be effective for engineers to employ.
- To establish what training can be employed to improve creative thinking of engineers.
- To design a methodology to test the hypothesis, including selecting a technique for implementation and developing a way to assess safety design in terms of the themes of *development* and *application* of solutions.
- To implement the research and report the results.

Chapter Two

Accident Prevention

2. Accident Prevention

The theory of the prevention of injury now gives priority to a concept known as *control at source*. For some time it has been established through common law that it is an employer's duty to establish and maintain a safe plant, premises, and a safe system. Nowadays these responsibilities are outlined by legislation. While a *safe system* has been required, the core meaning of what characterises such a system is best emphasised by the importance that legislation now accords the notion of *hazard* management. Control of hazards at *source* has been clearly expressed by legislation in many parts of the world. In particular the United States' legislation from 1970 and more recent Australian legislation, such as the Western Australian, Victorian and South Australian Acts, made the priority of hazard control very clear.

> *Each employer shall furnish to each of his employees employment and a place of employment which are* ***free from recognized hazards*** *that are causing or are likely to cause death or serious physical harm to his employee.*
> *(Occupational Safety and Health Act of 1970 (USA) s.5.(a)(1), emphasis added)*

> *The employer shall take all precautions necessary to* ***prevent the employee from being exposed to health hazards or accident risks****.*
> *(Work Environment Act 1977) (Sweden 1994), ch. 3 s. 2, emphasis added)*

> *The objects of this Act are— to* ***reduce, eliminate, and control the hazards*** *to which persons are exposed at work*
> *(Occupational Safety and Health Act 1984 (W.A.) s.5.(d), emphasis added)*

> *The objects of this Act are— to* ***eliminate, at the source****, risks to the health, safety and welfare of persons at work*
> *(Occupational Health and Safety Act 1985 (Vic.) s.6.(d), emphasis added)*

> *The chief objects of this Act are— to* ***eliminate, at the source****, risks to the health, safety and welfare of persons at work*
> *(Occupational Health, Safety and Welfare Act 1986 (S.A.) s.3.(b), emphasis added)*

The attention given to *control at source* represents a model of prevention known as the *safe place* approach. The extreme alternative is the *safe person* approach where people are encouraged to behave safely in a hazardous environment. Atherley (1975; 1978) seemed to be the first to employ the terms safe place and safe person.

> ***Safe place*** *strategies aim at eradicating danger by seeking safe premises, safe plant, safe processes, safe equipment, safe materials, safe systems of work, safe access to work, adequate supervision and competent and trained people.*
> ***Safe person*** *strategies aim at protecting certain people from danger by care of the vulnerable (pregnant women, the disabled and young persons); personal hygiene; provision, use and misuse of personal protection equipment; careful actions for safety of self and others on the part of people at work in danger; and caution towards danger generally.*
> *(Atherley 1975, p. 54)*

Atherley (1978) later defined the terms much more generally and said that safe place strategies place emphasis on the control of the work place whereas safe person strategies attempt to control the individual. Later authors such as the National Occupational Health and Safety Commission (NOHSC 1991d), in their program for introducing health and safety to undergraduate engineering students, and Stranks (1994) adopted the safe place / safe person terminology.

> *The term **'safe place'** refers to the design of workplaces, processes and operations which are intrinsically safe, that is, safety of persons within the workplace does not rely on appropriate behaviour patterns. The term **'safe person'** refers to the reliance on people's behaviour for their safety. (NOHSC 1990d, p. 19, emphasis added)*

> *Accident prevention strategies should thus be directed at, first, bringing about a reduction in the objective danger in the workplace, and second, increasing the perception of risk on the part of individual workers. This is brought about, in the first case. by the use of **'safe place'** strategies, and in the second case, by **'safe person'** strategies...*
> *(Stranks 1994, p. 144, emphasis added)*

In summary, the safe place model underpins current legislation in Australia and in many other countries. However its primacy has not always been so evident and even today there is strong adherence to the safe person philosophy. The progress in thinking has clearly been from a historically dominant safe person model to a situation today where that model is questioned and the safe place approach is given greater credibility. Given that over time the thinking has changed from the safe person to the safe place philosophy it is natural to begin this chapter by discussing *safe person* way of thinking; its history and problems.

2.1 The Safe Person Approach

The safe person approach to prevention is based on a premise that individual people are able to avoid accidents by appropriate behaviour. This approach retains its strong appeal among the general population and with some involved in specialist safety roles. However there is a growing core of opinion attesting to the unjustifiable focus on unsafe acts and the consequential attention given to behavioural modification as an effective strategy. Similarly, among safety writers there is a common rejection of the accident proneness theory. While rejecting the basis of the safe person model, many writers also point toward the misguiding influence this type of thinking has on preventative efforts. These issues are explored in the following pages.

2.1.1 Unsafe Acts and Unsafe Conditions: Unjustifiable Categories

Much of the focus of the prevention of injury from the mid 1800's to the early 1900's was concerned with the guarding of machinery. Given the great problems with machinery-based injuries it became customary to view the causes of accidents in the *machinery* or *non-machinery* dichotomy (for example; Stephenson 1926; Viteles 1932; Watkins & Dodd 1940). These terms seemed to be the foundation for a model later known as, *unsafe acts* or *unsafe conditions* (for example; Vernon 1936; Heinrich 1941; Denton 1982; Watson 1986; Stranks 1994).

The unsafe acts and unsafe conditions model seems to have had a powerful influence on the thinking in safety. Part of this acceptance may be attributable to the popularity of the work of Herbert W. Heinrich. Heinrich, an engineer working for an insurance company in the USA in the 1920's, studied 75,000 reports of accidents gained from insurance files and industrial records. In 1931 Heinrich first published *Industrial Accident Prevention*; a text based on his findings from the analysis of the accident reports. Heinrich's (1941) *domino* model (Figure 2-1) of the five factors that he thought represented the accident process has since become very popular. The five factors considered were as follows.

1. Ancestry and social environment.
2. Fault of person.
3. Unsafe act and/or unsafe mechanical or physical hazard.
4. Accident.
5. Injury.

(The Five Factors in the Accident Sequence, Heinrich 1941)

> *(1) Industrial injuries result only from accidents, (2) accidents are caused directly only by (a) the unsafe acts of persons or (b) exposure to unsafe mechanical conditions, (3) unsafe acts and conditions are caused only by faults or persons, and (4) faults of persons are created by environment or acquired by inheritance. (Heinrich 1959, p. 4)*

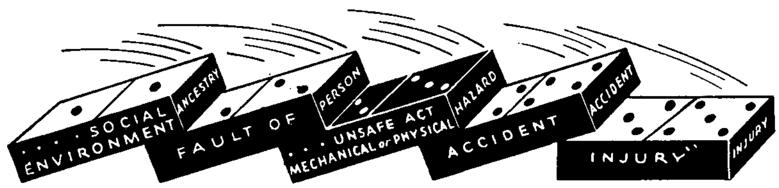


Figure 2-1 The Injury is Caused by the Action of Preceding Factors (Heinrich 1941)

According to Heinrich, the accident process was sequential. One factor lead to another and so on until the injury occurred. The dominoes represented this sequential and causal relationship. Heinrich thought that the central factor, and the key, to the accident sequence was the unsafe act or unsafe condition. As mentioned above, at the time Heinrich developed the model, this type of dichotomy in the cause of accidents was very common.

Within the sphere of this model it has been a well-entrenched perception that unsafe acts are the primary accident cause. Heinrich's study of accident reports found that 88% of accidents were the result of unsafe acts and 10% the result of unsafe conditions. Heinrich found that the remaining two percent were unpreventable and without apparent cause. From these statistics Heinrich centred preventative efforts on the unsafe act.

> *The unsafe acts of persons are responsible for the majority of accidents.*
> *(Heinrich 1941, p. 12)*

The general idea around the time of this work was that much had been accomplished with machinery safeguards and that the remaining, and growing problem, was with unsafe acts. It may be that Hienrich's analysis simply became evidence for a way of thinking widespread at the time. As evidence of the thinking of that time consider Eastman's comments from 1910. Eastman wrote a report based on the *Pittsburgh Survey*; a survey that examined fatalities in the district over a one year period. The resulting text chronicled the stories of the fatalities, the law, and family issues of a year of destruction mainly in the infamous railroad, mining, and steel industries. Eastman's characterisation of the archetypical response of an industrial manager shows how she found the victim blaming paradigm embedded among managers.

> *"So you've come to Pittsburgh to study accidents, have you?" says the superintendent, or the claim agent, or the general manager, as the case may be. "Well, I've been in this business fifteen years and I can tell you one thing right now,-95 per cent of our accidents are due to the carelessness of the man who gets hurt. Why, you simply wouldn't believe the things they'll do. For instance, I remember a man,"-and he goes on to relate the most telling incident he knows, to prove his assertion. (Eastman 1910, p. 84)*

Eastman (1910) stood apart as a sceptic among many writers who appeared certain that victims were the main source of the problems. For instance, Stephenson (1926) and Watkins and Dodd (1940) made the following comments.

> *To sum up, much has been done towards accident-prevention by the use of mechanical safeguards, and a little more may possibly be accomplished by this means. ... "The problem of accident-prevention to-day is largely a psychological one." Much may be done by*

education and propaganda, still more, probably, by scientific selection. (Stephenson 1926, p. 200)

If complete information were available, we should probably find that the greater number of accidents in industrial communities is caused, not by the absence of adequate safeguards, but by negligence, carelessness, want of instruction, want of thought, and a lack of appreciation of the dangers involved in the complex and intricate machine processes in modern industry. ...The workman himself, by his carelessness, may be responsible for a large percentage of accidents, or the negligence of his fellow workmen may be an equally accountable factor... accidents depend in the main on carelessness and lack of attention of the workers.
(Watkins & Dodd 1940, p. 340-341,)

The following quotes from the 1950's, 60's, 70's and 80's illustrate how the perception of the role of unsafe behaviour in accident causation then continued.

The ***'unsafe attitude'*** *is the most serious problem in accident prevention...*
(Scott 1953, emphasis added)

Good industrial accident records may be marred by ***personal carelessness or lack of cooperation. Irresponsible, inconsiderate, absent-minded, or incompetent*** *drivers cause more accidents than mechanical failure, highway conditions, or weather factors.*
(Blasingame, in The American Public Health Association 1961, p. xx, emphasis added)

... [the] five main causes of accidents which kill approximately 20,000 people each year in Britain ... were ***selfishness, lack of interest in others, inefficiency, bravado, and carelessness*** *... [and] it was vitally important to train young people to realise the necessity of* ***adjusting themselves to their environment and their equipment****. (Porritt 1965, p. 5, emphasis added)*

... Heinrich informed us of what is now painfully obvious and simple truth-that ***people, not things, cause accidents****. (Petersen 1978, p. 15, emphasis added)*

...we also know today that his [Heinrich's] concept was meaningful and extremely valid. ***People are the primary cause of accidents****. (Petersen 1984, p. 5, emphasis added)*

*In fact safety statistics suggest that **85% ... can be attributed to unsafe behaviour** alone. (Watson 1986, p. 20, emphasis added)*

Recently it has been demonstrated in Australian surveys of workers that the conviction about the role of unsafe behaviour remains entrenched. Biggins, Phillips and O'Sullivan (1988), Biggins and Phillips (1991) and Gaines and Biggins (1992) conducted surveys of workers in various states of Australia and showed a perpetuation of the careless worker theory. The surveys showed that approximately 50% of their study groups (98 health and safety representatives in Western Australia, 125 workers undergoing health and safety training in Queensland, and 82 workers undergoing health and safety training in the Northern Territory, respectively) believed *worker carelessness* was the main cause of accidents. An earlier evaluation of health and safety representative training by Else & Cowley (1987) found similar views. A survey commissioned by Worksafe Australia recently found that when asked to nominate the main cause of accidents, about 50% of a sample of 2000 working age people across Australia nominated *lack of training or education* or *worker carelessness* (ANOP 1995). Likewise a recent study of health and safety representatives in South Australia (Culvenor, Cowley & Else 1996) found that many of the 400 respondents (from a sample of 1200) indicated strong agreement that factors such as *carelessness* and *lack of training in how to behave safely* were important causes of accidents at their workplace. These surveys show that the victim-blaming paradigm remains strong among the general community and among health and safety representatives.

In summary, accident causation has been viewed through the spectacles of the *unsafe act* or *unsafe condition* model. Within this model, unsafe acts has been considered by many to make up the great majority of the problem. This is evident from the comments made by writers in safety, through the surveys mentioned above, and indeed in popular culture such as in discussions of safety in newspaper and television reports.

While still well believed in popular circles and even among workers involved in health and safety such as health and safety representatives, many authors have questioned

Heinrich's focus on unsafe acts and the usefulness of the classification of accidents with this model (for example; NSC 1959; ILO 1961; Blake 1953; Hammer 1976; ILO 1983).

> *In most industrial accidents, both an unsafe condition and unsafe act are contributing factors. ... It must be remembered, however that an unsafe condition, in addition to being a direct cause of accidents in itself, often can lead people to perform unsafe acts. Many times, an unsafe act is the result of poor machine design, inadequately planned method, and other engineering deficiencies.*
>
> *Experience shows that when an injury occurs, the unsafe condition often is not as glaringly evident as the unsafe act. Unless a careful study is made of the accident occurrence, the correctible physical hazard may escape notice.*
>
> *Elimination of a hazard due to an unsafe condition removes one of the accident-causing factors, and thereby reduces the likelihood of injury from an unsafe act. (NSC 1959, p. 4-4)*

The ILO proposed that a reworking of accident reports could easily result in *reversal* of claims about the ratio of unsafe act/unsafe condition statistics.

> *An accident is very seldom due to solely to unsafe behaviour. As already stated, accidents are usually caused by a group of circumstances; one of these may be unsafe behaviour, but in all probability unsafe conditions are present as well, and so it would be equally justifiable to classify the accident as due to unsafe mechanical or physical conditions. (ILO 1961, p. 25)*

Blake (1963) said that invariably both a poor condition and an unsafe act occur leading up to an accident, but all too frequently the unsafe behaviour is the centre of attention.

> *... in each case of injury both the factor of hazard and that of faulty behaviour are inescapably present... Too often, however, these fundamentals are over-looked and sole attention is given to the unsafe act. (Blake 1963, p. 56)*

In the report titled *Bitter Wages: Ralph Nader's Study Group Report on Disease and Injury on the Job*, Page and O'Brien (1973) commented that the unsafe behaviour model is a hoax with little real basis.

One of the most persistent of the arguments mounted against broad federal involvement in the struggle against work accidents and diseases emerged from the notion that the overwhelming majority of job injuries result from worker carelessness; therefore, the proper and better approach to occupational safety is to educate employees, rather than impose mandatory standards on employers.

Some companies have gone to great lengths in their efforts to "teach" safety and motivate workers to be careful...

A closer look [at statistics] reveals that the worker-carelessness theory is a hoax. It is a version of the "nut behind the wheel" argument used in the unsuccessful attempt to stop legislation giving the federal government authority to impose performance standards upon automobiles. As hoary as the work safety movement itself, the worker-carelessness argument has a very shaky basis in reality. Although one cannot deny that some work accidents are causally related to worker carelessness, this does not mean that they all are. Nor does it mean that the frequency and severity of these accidents cannot be substantially reduced by designing the work environment and work practices to take human failings into account. (Page & O'Brien 1973, pp. 145-146)

Johnson (1973), in his text on risk management, suggested that behind many so-called unsafe acts lie a lack of human factors in design.

Experience indicates that accidents previously attributed to "unsafe acts" are often reduced after human factors review and correction. This implies that the previous description of "unsafe acts" was largely incorrect, and that we really had an "error-provocative" situation, and therefore an "unsafe condition." (Johnson 1973, p. 273)

In his text on accident prevention and engineering, Hammer (1976) commented that reclassification of Heinrich's data could easily result in a reversal of ratio of unsafe acts to unsafe conditions. Hammer wrote that *'...until a few years ago it was considered that if a man was involved in an accident it was probably his fault.'*. Hammer illustrated his point with the example that plane crashes were once generally blamed on pilot error. Hammer said that this perception was difficult to justify when the Armed Services investigated crashes of ballistic missiles that had no pilot to blame; they therefore concluded that the design systems were inadequate.

In his 1991 review and overview of safety concepts, Thomas indicated that Hienrich's model had been useful in many ways but had a fundamental weakness in its terminology.

Much good work resulted from the use of this model. Its weakness is the result of the use of the highly subjective word unsafe. (Thomas 1991, p. 100)

The word unsafe is subjective and thus can be self perpetuating. A person is always present at some point in the failure that leads to an accident and often the person most proximate in time and in space is the victim. Beginning an accident investigation with the unsafe act model in mind invariably implicates a person (normally the victim) in the cause. Thus the unsafe act paradigm is self-perpetuating. Given a perception that unsafe acts cause accidents, it follows that this label is simple to ascribe to virtually all accidents. This is the case not only in occupational accidents but has been a common flaw in thinking about road accidents, as Ralph Nader indicated.

Today almost every program is aimed at the driver-at educating him, exhorting him, watching him, judging him, punishing him, compiling records about his driving violations, and organizing him in citizen support activities. Resources and energy are directed into programs of enforcement, traffic laws, driver education, driver licensing, traffic courts, and vehicle inspection. The reasoning behind this philosophy of safety can be summarized in this way: Most accidents are in the class of driver fault; driver fault is in the class of violated traffic laws; therefore, observance of traffic laws by drivers would eliminate most accidents.
(Nader 1965, p. 235)

There is considerable doubt about the usefulness of attributing accidents to an unsafe act alone, or an unsafe condition alone. Within such a framework the attribution of a great many accident to unsafe acts has been largely arbitrary. As a consequence, the model is rejected in many circles and considered an unhelpful tool for prevention.

2.1.2 Safe Behaviour Promotions: The Myth of the Careless Worker

The accident prevention literature from the early 1900's focussed heavily on the promotion of safe-behaviour (for example; Stephenson 1926; Vernon 1936; Watkins & Dodd 1940; Heinrich 1941). This was a natural extension of the belief that unsafe behaviour lead to most accidents.

As mentioned, Heinrich suggested that the unsafe act or unsafe condition was the central factor in the accident sequence. The theory of prevention that followed was then to remove the central factor to interrupt the sequence (Figure 2-2).

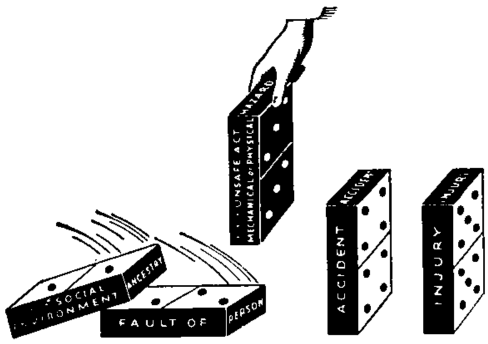


Figure 2-2 The Removal of the Central Factor Makes the Action of Preceding Factors Ineffective (Heinrich 1941)

Tracing the dominoes backward it was believed that unsafe acts were causally linked to faults of persons created by environmental conditioning (learned behaviour) or acquired by inheritance. The means to prevention were then two fold; one of weeding out those who had an inherited *accident-proneness* (discussed later) and secondly by behaviour and attitude change programs. Scott (1953), in a brief commentary about attitude problems, warmed to the risk homoeostasis theory when he maintained that improving environmental conditions should be avoided as it may worsen the safety situation by creating an illusion of safety and thus lead to a less alert attitude and hence more accidents! There was a great belief among many commentators such as Vernon (below), a psychologist, and Blasingame (below), then president of the AMA, that maintaining a safe state of mind would be useful in preventing accidents.

Everyone is bound to be exposed almost every day to risk of accident in the home and on the roads, while a part of the population is exposed to additional risks in factories, coal mines and other places. No one can possibly keep himself always at the maximum degree of alertness and attention, and it inevitably follows that when attention relaxes liability to accident increases. Everyone should therefore endeavour to acquire the habit of increasing his alertness at time when specially exposed to risk, and this habit is best acquired by long-continued education. The earlier in life this is begun the more effective is likely to be. The safety habit should become to some extent instinctive and subconscious, so that exposure to a risk results in the potential victim's taking almost automatically the appropriate steps to avoid it. (Vernon 1936, p. 325)

The physician is also challenged by the psychological aspects of accident prevention. He is conscious of his responsibility to help control the effects of anxiety, frustration, sorrow, depression, compulsions, confusion, fear, rage, or resentment on the individual's judgement and coordination, whether at the wheel, afoot, or while working or playing about the home, or on the farm. (Blasingame, in The American Public Health Association 1961, p. xx)

More recent writers now tend to point out that changing behaviour is really more central to the argument than the changing of attitudes. Consequently recent journal articles have promoted schemes that use *training* or *coaching* to hopefully change behaviour and thus avoid accidents (for example; Grummon and Stilwell 1984; Watson 1986; Ashton 1994; Hidley and Krause 1994; Geller 1995). These authors have suggested that unsafe behaviours be identified, corrected and monitored by training and coaching. Grummon and Stilwell (1984) actually promoted *teasing* as an accident prevention measure. They suggested that teasing will prevent unsafe acts by engendering peer pressure to be safe.

The thinking behind behaviour and attitude safety programs is that promotion will lead to a subsequent motivation to be safer. Posters are a common example of attempting to reduce accidents by simply promoting the *safety cause*.

Figure 2-3 Safety Poster Competition Third-Prize
Winner, UK National Coal Board (Wood 1965)

Figure 2-4 WorkCover's Current Safety Slogan (*WorkWords*, no. 18, 1996)

Figure 2-3, a prize winner among 2,390 entries in a safety poster competition organised by the National Coal Board in the United Kingdom in 1962 (Wood 1965), and Figure 2-4, the similar slogan currently promoted by the WorkCover Corporation here in Victoria, represent most succinctly the technique of encouraging a safe mindset as a means to prevention. Unfortunately the older poster shows a picture of a worker; implying the importance of their conscious effort. The more recent poster is hopefully directed at management level. This would certainly be in keeping with today's legislation however there is nothing in the promotion to indicate that management is the target and it thus could be mistakenly construed as a call for workers to work safely.

As noted above, a number of research studies have shown that there is a strong perception that worker behaviour is the cause of accidents (refer to section 2.1.1; Else & Cowley 1987; Biggins, Phillips and O'Sullivan 1988; Biggins and Phillips 1991; Gaines and

Biggins 1992; Culvenor, Cowley & Else 1996). From such a belief stems a strong temptation to employ exhortations and encouragement in the hope that workers can be made to modify their behaviour. However, Kinnersly (1973) and Mathews (1986; 1993), whose work became standard texts for workplace health and safety representatives in the United Kingdom and Australia respectively, ridiculed schemes that aimed to achieve prevention by attempting to encourage safe behaviour rather than addressing the environment. Kinnersly said that the schemes address the problems too late. *'Exhortations and posters start to fly after the ill-conceived work system has been set up and accepted as quite normal.'* (1973, p. 196) while Mathews (1986) derided bonus schemes that purport to encourage safe behaviour with some kind of reward. Mathews related an example of how one scheme relied on the incentive of a free chicken as an enticement for a period of no lost-time accidents. These kind of schemes seem absurd. If someone was in control of their own injuries (as per the unsafe act theory), how would a free chicken possibly significantly add to the incentive of not losing a personal body part? Kinnersly and Mathews attributed such schemes to the *myth of the careless worker*.

It is possible to draw some parallels with these approaches in occupational safety to those in public health and safety. For some time, commentators have noted that the vagueness and myths surrounding disease hampered the development of reliable public health interventions (for example; Rapoport 1961; Haddon 1973a; Wigglesworth 1978). Both Haddon and Wigglesworth drew examples from the times of the European plague where there was thought to be a link between the disease and the loose morals and emotions of the victims. For instance a German physician recommended avoiding emotions of the mind such as jealousy, anger, hatred, sadness, horror or fear, licentiousness, and so on, while some regulations in Germany, in the 1500's prohibited *immoral* behaviours such as gambling, drinking and cursing (NOHL 1926). These controls were obviously wrongly directed as we now know that the disease was controlled by focussing on the control of bacteria, mainly by better sanitation.

Like earlier writers above, Kjellén and Hovden (1993) recently commented that accidents were often viewed as being a fatalistic predisposition of people with an inherent fault.

In older days, accidents were often viewed as being outside the scope of human control, i.e., they were determined by fate or were a punishment of sins and lack of moral standards. (Kjellén & Hovden 1993, p. 418)

However odd the plague stories sound now there are parallels with approaches today. For instance, the Victorian Traffic Accident Commission (TAC) use violent images of the supposed consequences of the *lack of concentration* and *impatience* when driving. Their relationship between emotions such as impatience and road crashes seems similar to the notion that bad morals once caused major plagues. Nohl (1926) described the story of a servant in plague-ridden Germany who contravened regulations, subsequently contracted the disease and then died before being punished. To send a message to others she was supposedly exhumed, executed, and then burnt, after her death. While this story is rather extreme, the *principle* is not unlike modern day efforts to chastise people for their behaviour. This way of thinking seems to be popular and may appeal to a sense of righteousness and punishment, but the link to the reduction of injury is illogical and unsubstantiated. In a review of the relationship between insurance and prevention, Luntz (1994) said that although there is strong community support, and a community perception that the TAC campaigns are successful, in terms of the simultaneous reductions in the road toll while the campaign has been running; *'...it cannot be shown conclusively that the advertising campaign has been causally relevant*'.

Ralph Nader, a road safety enthusiast, who has arguably done more to influence safety in automobile design than any other individual, described how the National Safety Council in the United States continually berated drivers for the behaviour in the hope that this would prevent accidents, much like the predictions given great credibility on news programs now.

While the AAA may occasionally raise a voice that is displeasing to the automobile industry, that "hub of the safety movement", the National Safety Council, remains the unswerving keeper of the traditional faith. Almost everyone in America has heard the council's repeated injunction that to be safe one simply has to be careful. Before every holiday weekend, the council makes its highly publicized prediction of the number of highway deaths. Should the prediction be exceeded, it shows how important are the *council's warnings against carelessness; if the prediction exceeded the actual toll, then the council concludes that its warning made people drive more carefully. Either outcome serves to nourish the council's image of always being on the side of the angels. The council gets enormous publicity as the nation's caretaker of traffic safety. Since its founding in 1915, the council has saturated the country with slogans, printed material, and broadcasted exhortations for safer driving. It has helped to form state and local safety councils, accrediting seventy-two of them as council affiliates, all devoted to persuading the public to drive carefully.* ***This may be a generally useless endeavor but it is not a harmless one. What seems to fill a need in form succeeds very well in excluding alternative methods that could fill it in fact.***

(Nader 1965, p. 261, emphasis added)

It could be said that there remains unreasonable attention given to the culpability of workers for their own injuries. Recent surveys show a strong belief in this way of thinking. Similarly, public efforts in road safety seem to reinforce this approach. It could not be said though that the model of bad worker behaviour and the subsequent encouragement of good behaviour is a very competent application of occupational legislation throughout Australia. Whether effective or not, and I would argue not, it needs to be recognised that this approach does not coincide with what the law requires.

2.1.3 Accident-Proneness: A Case of Mistaken Identity

Along with learnt reckless behaviour, it was thought that some unsafe acts could be traced back to unchangeable psychological traits. This theory labelled workers with apparently higher than normal accident rates as *accident prone*. Given that it was an apparently unchangeable inherited characteristic, the problem was thought to be best handled by avoiding the employment of this type of person. The theory finds little support now.

Powell, Hale, Martin and Simon (1971) investigated over 2000 workshop accidents in the United Kingdom and found that personal characteristics had little to do with accident rates.

Cronin's (1971) study of 1800 industrial accidents showed no relationship between age of employee even though attributing high accident rates to young and old people was popular at the time (and continues to be popular).

Leigh (1986) studied accident data gained from around 5000 subjects in national surveys in the USA in 1978 and 1979 to examine the relative importance of individual and job characteristics in accident prediction. Through analysis of the data Leigh concluded; '*The results suggest that job characteristics are better predictors of industrial accidents than personal characteristics*' (Leigh 1986, p. 216). That is, the job environment and system are predictors of accidents rather than the personal features of the victim.

Mohr and Clemmer's (1988) study of the work history records of about 1000 workers in the offshore (US) oil industry found little evidence that the study of accident proneness was a useful accident prevention measure. They commented *'From the results of the present and cited studies it is unlikely that overall injury rates in the workplace can be effectively reduced by screening out workers with excessive numbers of injuries in any given time period despite the intuitive appeal of this approach*' (Mohr & Clemmer 1988, p. 127).

If accident proneness was real, human resource managers would have the task of making this selection. An examination of human resource texts indicates that human resource specialists generally agree that they have no way to measure the phenomenon (for example; Sikula 1976; Robbins, Low & Mourell 1986; Schuler, Dowling & Smart 1988). Sikula (1976) agreed with many safety writers that attribution of accidents to *accident proneness* is a statistical misunderstanding that has retarded the progress of accident analysis.

Evidence seems to disagree with Heinrich's assertion that inherited personal characteristics are related to accident rates. MacIver (1961) many years ago commented that accident proneness was then discredited as a useful tool in accident prevention. Many authors since have suggested that blaming people with an apparent over-representation in accidents is a sham based on statistical misunderstanding (for example; Energy Research and Development Administration 1977; Kletz 1990c). Kletz illustrated the potential for being mislead by accident statistics with the following example.

Assuming 100 accidents per year were distributed randomly among 200 workers at a single factory, the Poisson equation predicts that 121 people will have no accidents, 61 will have one accident, 15 will have two accidents, and 3 will have three or more accidents.

The mean accident rate per person is 0.5 per year. It is simple then to be mislead by the fact that three people have had six times the average number of accidents, and that 10% of the workforce had 40% of the accidents. These type of statistics are true but indicate incorrectly that there's something accident prone about these people. There is nothing different about these people as the accident rates are merely the result of chance.

In summary many writers have dismissed the *accident-prone* worker theory (for example; MacIver 1961; McFarland & Moore 1961; Suchman & Scherzer 1964; International Labour Organisation 1971; Wigglesworth 1984). Often it has been suggested that the misdirected attention directed toward accident-prone personality in accident rates is due to a misunderstanding of statistics (MacIver 1961; McFarland & Moore 1961; ERDA 1977; Kletz 1990c). Furthermore one could easily draw a parallel between the study of accidents and the study of quality where Edwards Deming (1982) went to pains to explain the fallacy of rewarding and punishing staff based on similar statistical ignorance.

2.1.4 Beginning from Inherent Hopelessness

Accident:
an undesirable or unfortunate happening; casualty; mishap
anything that happens unexpectedly, without design or by chance
the operation of chance
a non-essential circumstance; occasional characteristic
(The Macquarie Dictionary 1985)

The popular, or dictionary-based, definitions of *accident* quote words like unexpected, unintentional, damage and chance. Scientific or professional definitions are often not the same as popular definitions. For instance terms like stress and strain have particular meanings to engineers and different meanings to the general population.

A scan of the terminology employed in the definition of *accident* from a variety of safety literature over a wide time span shows that unplanned, unintended and unexpected are often used to describe the phenomena of accidents (Table 2-1). Many *scientific* definitions thus conform to the popular (dictionary) definition.

Accident Definitions	***Source***
Unplanned	*Heinrich 1941; Blake 1963; Wigglesworth 1972; James 1983; Bamber 1994; West 1994; Stranks 1994*
Unintended	*Blake 1963; Yellman 1987; NSC 1990; Stranks 1994*
Uncontrolled	*Heinrich 1941*
Unexpected	*Kuhlmann 1986; Bamber 1994; West 1994; Stranks 1994*
Undesirable	*Harms-Ringdahl 1993*
Sudden	*Berman & McCrone 1943*

Table 2-1 Terminology in Accident Definitions

The view that accidents are not planned encouraged a very narrow view of accident causation. Notably, while Stranks employed the terminology listed above (Table 2-1), he emphasised that accidents are unforeseen by the *victim*. Thereby implying that those with a wider understanding of the hazards with which the victim is associated, for example management, should have the ability to foresee, predict and so on.

Haddon, Suchman and Klein (1964) commented that much of the thinking about accident causation is bound in folklore rather than systematic thinking.

> *It is not uncommon, for example, to encounter physicians, lawyers, economists, and other men whose training has involved analytical thinking and the continuous search for cause who believe that accidents are "acts of God" that "just happen," and that "lightning never strikes twice",* ***that accidents are as uncontrollable as the weather****; that, in short, accidents somehow mysteriously defy any kind of systematic study beyond mere tabulation.*
> *(Haddon, Suchman & Klein 1964, p. 6, emphasis added)*

As Brauer (1990) discussed in the text for engineering students, *Safety and Health for Engineers*, the most obvious lack of science in accident analysis is in the use of terms such as, unplanned, uncontrolled and unpredictable. Defining accidents as unpredictable means that by definition there is no possibility of prediction; thus no possibility of control or prevention. Similarly, Gibson suggested that the *unpredictable* approach is fatalistic.

> *Defined as a harmful encounter with the environment, an accident is a psychological phenomenon, subject to prediction and control. But defined as an unpredictable event, it is by definition uncontrollable. (Gibson 1961, p. 87)*

If accidents are unpredictable, then they are also uncontrollable and unplannable. Obviously this is not true and some authors point out the fatalism of considering accidents to be unpredictable (for example; Gibson 1961; Bird & Loftus 1976b; Terry 1991).

Many authors, from an engineering standpoint, have lamented the lack of forethought by engineers at the design stage. Engineers have a clear opportunity to thwart accidents via user-friendly design; design sympathetic to humans rather than in conflict with humans.

> *Engineers have many opportunities to eliminate or reduce unsafe conditions. ...* ***Engineers also have many opportunities to minimize unsafe acts****.*
> *(Brauer 1990, p. 18, emphasis added)*

> ***Designers have a second chance****, opportunities to go over their designs again, but not operators ... Plants therefore should be designed, whenever possible, so that they are user-friendly ... so that they can tolerate departures from ideal performance by operators.*
> *(Kletz 1990c, p. 3, emphasis added)*

> *Nearly all accidents are caused by some event or physical phenomenon that was* ***entirely predictable at the design concept stage****. The reasons as to why such obvious potential hazards are not identified or catered for are numerous. However, all too often the reason is 'we didn't think of it'. (Terry 1991, p. 21, emphasis added)*

> *... modification of products or the physical surroundings is the most effective strategy for injury prevention. (Torell & Bremberg 1995, p. 71)*

There is therefore substantial opinion that use of terms like unplanned, uncontrolled, unpredicted and so on, in the definition of *accident* leave the process of planning for the prevention of these accidents unplannable, uncontrollable and unpredictable. Furthermore there is a recognition that many so-called unsafe acts are the result of design inadequacy and thus designers are in the best position to minimise the opportunities for, and outcomes of, operator mistakes.

2.1.5 Misguiding Preventative Action

Kinnersly (1973) claimed that careless worker theory causes workers to accept responsibility for accidents and thus make little effort to encourage management to improve systems. Many authors have suggested that management finds it convenient to be absolved of responsibility if the blame or fault of an accident can be attributed to someone else, often the victim (for example; Kinnersly 1973; Wigglesworth 1978; Kletz 1985; Cohen & Cohen 1991). Kletz, an engineer and well-known writer in safety, wrote that attributing accidents to human failing is *'...comforting for managers. It implies that there is little or nothing they can do to stop most accidents'* (1985, p. 1).

The main problem with the *careless worker* theory is that it points prevention efforts the wrong way. In his discussion of accident causation within the overall framework of industrial safety, Blake (1963) criticised Heinrich saying that the classification system he used was an over simplification and *'had the very unfortunate effect of drawing attention away from the even more important fact that the first and basic approach to injury prevention is and always should be one of hazard reduction or, if possible, complete elimination'* (p. 60). The ILO (1983) concluded that the approach of fixing blame on unsafe acts has done little in the area of prevention. *'The onus is often incorrectly put on the worker, and the conditions that have resulted in the unsafe act are not given full consideration.'* (p. 103). The following comments from Chapanis (1965), Emerson (1985), Kletz (1985), Office of Technology Assessment (1985), Hale (1990a) and Thomas (1991) demonstrate a growing belief that the attention placed on unsafe acts in the past has been harmful to the development of reliable solutions.

> *Accident statistics compiled by insurance companies on home, street, railway and industry accidents are full of causes such as carelessness, faulty attitude, and inattention. Although labels such as these appear to tell us something, they really don't. Everyone is inattentive at some time or other, and to say that an accident was caused by inattentiveness gives us no clue whatsoever about how we could have prevented it. (Chapanis 1965, p. 9)*

> *This human error fault concept provided the greatest impediment to the development of safer design considerations because of the widespread belief that human error is the cause of most accidents. Terms like unsafe act, unsafe condition after Heinrich and his ratio of "88 human errors: to 10 design problems: to 2 acts of God" have retarded the thinking of members of the safety profession in recent years. A distressing number of safety practitioners held the belief that human error caused most accidents. (Emerson 1985, p. 22)*

> *Accidents are due to human failing. This is not untrue, merely unhelpful. (Kletz 1985, p. 2)*

> *The traditional partition between unsafe acts and unsafe conditions unfortunately often draws attention away from the job or equipment redesigns that can remove or minimize hazards. (OTA 1985, pp. 70-71)*

In other words behavioural rules cannot be used to patch over bad design decisions. (Hale 1990a, p. 18)

This approach [unsafe acts and unsafe conditions] has bewildered the safety movement for a long time, particularly when coupled with some early research work which indicated the prime causes of industrial accidents as unsafe personal acts. This lead to undue emphasis on safety training as the most appropriate remedy to the detriment of removing hazards at their source by engineering means. (Thomas 1991, p. 100)

Ironically, Heinrich pointed to the weakness of behavioural controls.

In the same breath it can be truthfully said that although man failure causes the most accidents, mechanical guarding and engineering revision are nevertheless important factors in preventing most accidents. (Heinrich 1941, p. 18)

...the guarding of machines and hazards has been and always should be a fundamental of a complete safety program. Incidentally, guarding and other action of an "engineering-revision" nature often provide an immediate remedy even for accidents chiefly caused by man failure. (Heinrich 1959, p. 34)

Kletz (1993) said that the notion of unsafe act or human error seems to contaminate prevention to the point where it should not be listed as a cause at all when undertaking an accident analysis. The most well-known studies to devalue the human error concept has been those by Fitts and Jones in the late 1940's (Fitts & Jones 1961a; 1961b). Fitts and Jones analysed errors by civilian and military pilots. Five-hundred pilots returned questionnaires related to control operation errors and instrument reading errors. The main error types in the operation of controls (1961a) were *substitution or wrong control* (50%), *wrong adjustment* (18%), *forgetting or not operating a control* (18%), and *reversal, unintentional activation or unable to reach* (14%). Fitts and Jones (1961a) concluded that more than 50% of the errors were related to a lack of uniformity in the location and operation of controls. The errors in instrument reading (Fitts & Jones 1961b) consisted of misreading multi-revolution indicators (18%), reversal errors (17%), signal interpretation errors (14%), legibility errors (14%), substitution errors (13%), using inoperative instruments (9%), and an assortment of other errors (15%).

All but the *inoperative instrument* errors could have been easily attributed to pilot error. From this point a program of pilot training or maybe even discipline would have been likely. However Fitts and Jones took quite the opposite approach.

> *Aircraft accidents usually are classified as due to pilot error, to materiel failure, to maintenance, or to supervision, with a large proportion of all accidents attributed to the "pilot error" category. It has been customary to assume that prevention of accidents due to materiel failure or poor maintenance is the responsibility of engineering personnel and that accidents due to errors of pilots or supervisory personnel are the responsibility of those in charge of selection, training and operations. The present study was undertaken from a different point of view; it proceeded on the assumption that* ***a great many accidents result directly from the manner in which equipment is designed*** *and where it is placed in the cockpit, and therefore can be eliminated by attention to human requirements in the design of equipment. (Fitts & Jones 1961a, p. 336, emphasis added)*

Based on military research into control design, Fitts and Jones made detailed explanations of the types of redesign that could minimise the types of errors that had been common in the past. In general they suggested that uniformity of controls, and natural direction principles in the operation of the controls and instruments.

> *Substitution errors can be reduced by: (1) uniform pattern arrangement of controls; (2) shape-coding of control knobs; (3) warning lights inside the appropriate feathering button; and (4) adequate separation of controls. (Fitts & Jones 1961a, p. 333)*

> *Reversal errors can be eliminated almost entirely by adherence to uniform and "natural" directions of control movement. (Fitts & Jones 1961a, p. 333)*

Further to their application of engineering solutions to *human error* problems Fitts and Jones debunked some myths about the distribution of errors among the *inexperienced* or *accident prone*. They found errors to be distributed across all age and experience groups.

> *Practically all pilots of present-day Army Air Force aircraft,* ***regardless of experience, or skill****, report that they sometimes make errors in using cockpit controls.*

(Fitts & Jones 1961a, p. 333, emphasis added)

> *Instrument-reading errors are not confined to any single class or group of pilots* ***or to any particular experience level****. (Fitts & Jones 1961b, p. 360, emphasis added)*

Fitts and Jones (1961a; 1961b) demonstrated that defining an accident as due to human error did not provide a reason to embark on training or attitude changing programs. Their research clearly showed that accidents as a result of human error can be reliably prevented by switching the focus back on to the design. Design can be used to prevent, and mitigate the effects of, predictable human errors.

Nader (1965) placed similar attention for the prevention of road trauma firmly on the makers of the motor cars and in the following quote drew support from the Federal Highway Administrator of the time, who suggested that behaviour based programs have the unfortunate effect of discouraging more reliable methods of prevention.

> *"Perhaps the time has come," Mr. Whitten said, "to examine some of our present safety programs and some of our present safety concepts. The truth, as I see it, may be painful. ... I am concerned about the great amount of energy being devoted to 'hard sell' efforts to reform the driver-to scare or shame him into being a better one.* ***I believe we have exhausted the value of this continuing assault on human nature. And I have grave doubts that it works****. ... In many cases haven't we given the driver a task beyond the capacity of his senses, nerves, and muscles? ...*
> *"WE must face up squarely to this premise: the majority of drivers and performing as well as we can reasonably expect, under existing conditions. From that premise it is logical to reason that the conditions must be changed-we must improve the road, the vehicle, and the basic control measures of the system." (Nader 1965, p. 293 drawing on Rex Whitten, US Federal Highway Administrator 1963, emphasis added)*

> *...* ***our attention is being distracted and our energy is being diverted*** *from the essential things we could and should be doing to reduce the traffic accident toll.*
> *(Whitten, in Nader 1965, p. 293; emphasis added)*

The absence of any positive value of behaviour-based programs is only part of the problem. The continued promotion of the safe person approach hampers the strengthening and implementation of safe place measures. Rather than being motivated to implement a reliable safe place control, employers, employees, engineers, governments, and anyone else, could be excused for continuing to be exasperated by the apparant unwillingness of people to avoid injury.

2.1.6 Summary: Problems with the Safe Person Approach

The safe person strategy springs from the largely arbitrary classification of accidents as unsafe acts or unsafe condition, with a bias toward unsafe acts. The emphasis on unsafe acts has lead to campaigns focussing on either a dubious process of selecting-out accident prone people or on changing individual behaviour. While these may appear to address the problem, they make no actual change to the system and rely on the continuing active vigilance of those at risk.

2.2 The Safe Place Approach

The safe place approach relies on a different set of definitions and methodologies to the safe person approach. The safe place approach to prevention concedes that different human behaviour may have avoided accidents, but that attempting to encourage this type of appropriate behaviour to avoid further accidents is not as effective as improving the safety of the system itself. The safe place approach or the *hazard* management approach to the prevention of accident rests on a number of key models and theories.

2.2.1 Control at Source

The concept behind the hierarchy of control is that the most effective means of hazard control is to target the hazard source. This concept is now a key feature of occupational health and safety legislation in Australia and in other countries. As mentioned above, the United States' legislation from the early 70's indicated that workplaces should be *free of hazards*. More recent Australian legislation expresses the concept of control at source explicitly (especially the Western Australian, Victorian and South Australian legislation).

The hierarchy of control stems from the study of occupational hygiene, where it became customary to view the source of contamination as the hazard. The process was modelled as; *hazard source* ➔ *pathway* ➔ *receiver*. Consequently it was realised that the most effective prevention was to place the attention for control firmly on the hazard source (Hamilton 1929). Hamilton, recognised as a pioneer figure in the establishment of the hygiene profession, made it clear that controlling the source of the problem was the only reliable way to preventing occupational diseases. Personal protection is usually near to the last resort as it does not address the problem source and its reliability has been shown to be poor. Personal protective equipment is also a lower order control as there is no supplemental control for this method; there can be no back up as it is the last line of defence. According to Hamilton protective equipment was suitable for emergency situations but not for every-day control.

> *If this [mode of entrance into the body] is by way of the inspired air, the prevention of fumes and dust becomes the matter of first importance. Whatever money is available for factory hygiene must be expended first on mechanisms to prevent poisoning of the air...A mask, carefully selected for the particular poison against which protection is needed, should be provided for emergency use, during short periods only, in all places where there is danger of fumes or dust, but to place one's trust in masks for the continual protection of men is simply to* ***close one's eyes to unpleasant facts****. (Hamilton 1929, p. 538, emphasis added)*

These sentiments are now echoed by various legislation, such as the Swedish *Work Environment Act 1977*.

Personal protective equipment shall be used when adequate security from ill-health or accidents cannot be achieved by other means.
(Work Environment Act 1977 (Sweden 1994), Ch. 2. S. 7)

From the *hazard source* ➔ *pathway* ➔ *receiver* model arose a systematic approach to prevention known as the *hierarchy of controls*. Bloomfield (1936) and Brandt (1947) outlined the following hierarchies for the management of occupational hygiene.

Early Hierarchies for the Prevention of Occupational Disease

Bloomfield (1936)	***Brandt (1947)***
1. Substitution of a non-toxic material for the toxic one.	*1. Eliminating the sources of contamination or reducing the amount*
2. Isolation of the harmful process.	*2. Prevention of contaminant dispersion*
3. Wet methods in the case of some dusty processes.	*3. Protecting the worker*
4. Exhaust ventilation.	
5. Respiratory protection.	

Table 2-2 Early Hierarchies for the Prevention of Occupational Diseases

Bloomfield (1936) commented that the hierarchy is a general model for prevention rather than a fixed set of specific rules.

No set rules may be established for the mechanical protection to be instituted in an attempt to control an industrial poison. Specific conditions encountered in a plant will determine the type of protection to be employed. In general there are five methods which may be attempted in the minimization of an industrial poison... (Bloomfield 1936, p. 662)

The concept of *control at source* has been often illustrated by models such as Figure 2-5 and Figure 2-6. These are used to demonstrate more clearly the concept of the hazard source, pathway and receiver. The pictorial models illustrate that placing a control near to the source minimises the potential problem while barriers at the person are a last resort.

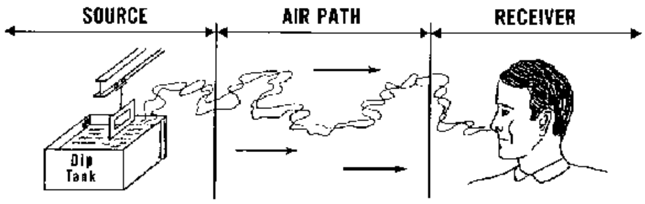


Figure 2-5 Source, Pathway, Receiver Model (from NSC 1971)

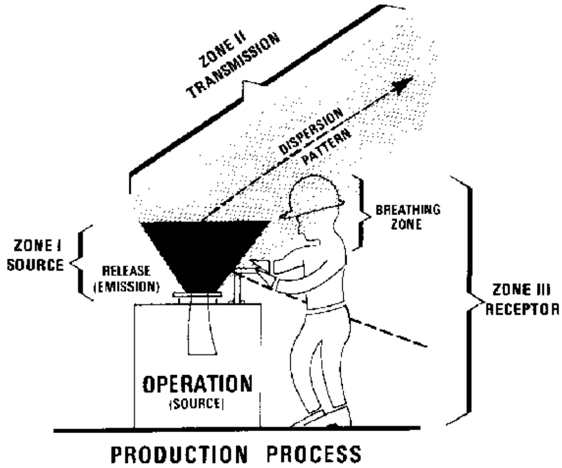


Figure 2-6 Conceptual Model of the Three Zones of Influence to Control Workplace Hazards (US DHHS NIOSH 1984)

In the post-war period there was much comment about the relationship between the prevention of injury and established approaches in the area of occupational hygiene (for example; McFarland & Moore 1961; Suchman 1961). Around this time discussion began about the application of the hierarchy of control to injury prevention.

> *The engineer should include in his planning and follow-though such measures as will attain one of the accident prevention goals listed as follows (in the order of effectiveness and preference):*
>
> 1. *Elimination of the hazard from the machine, method, material, or plant structure.*
> 2. *Guarding or otherwise minimising the hazard at its source if the hazard cannot be eliminated.*
> 3. *Guarding the person of the operator through the use of personal protective equipment if the hazard cannot be eliminated or guarded at its source.*
>
> *(National Safety Council 1959, p. 4-2)*

Nowadays the hierarchy of control is seen as a general approach to health and safety. This model is the central theme of a multitude of the state-based regulations and codes of practice throughout Australia. The hierarchy has been adopted by the National Occupational Health and Safety Commission in many standards and codes of practice such as those covering plant (NOHSC 1994b), manual handling and occupational overuse syndrome (NOHSC 1990a; 1990b; 1994a) and noise (NOHSC 1993a; 1993c) and recently by Standards Australia and Standards New Zealand in the draft standard *Occupational Health and Safety Management Systems* (SA/SNZ DR 96311 1996).

There are many versions of the hierarchy such as those within the regulations and codes of practice above. Table 2-3, Table 2-4 and Table 2-5 show a historical account of various versions of the hierarchy of control (not including the many versions that now appear in documents such as those mentioned above). These tables show a variety in terminology and the number of points, however they show commonality of approach along the following lines and modelled on the process shown by Figure 2-7.

1. Reducing the hazard source.
2. Containing the hazard source.
3. Separation of the hazard and people (by barriers, distance, etcetera).
4. Protecting the worker with PPE or relying on safe behaviour.
5. Post-Event strategies

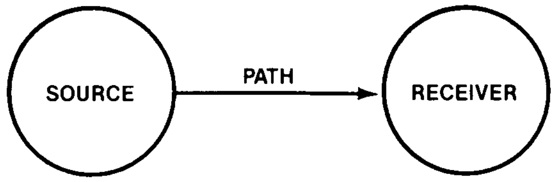


Figure 2-7 Three Major Areas Where Hazards can be Controlled

Focus of Control	Bloomfield 1936	Heinrich 1941	Brandt 1947	NSC 1959	Haddon 1963	Surry 1968	NSC 1971
Source Reduction	• Substitution		• Elimination or Reduction	• Eliminate Hazard	• Eliminate Energy	• Eliminate Task • Eliminate/Substitute Energy	• Substitution • Change Process
Containment	• Isolation • Wet Methods	• (2) Engineering Revision	• Prevention of Dispersion	• Minimise Hazard / Prevent Release	• Prevent or Modify Energy Release		• Isolation • Wet Methods
Separation	• Exhaust Ventilation				• Separation • Barrier	• Remove Recipient • Barrier • Modify Energy Transfer	• Local Ventilation • General Ventilation
Behaviour & Worker Protection	• PPE	• (1) Education • Placing • Discipline • Medical Treatment • Psychology	• Worker Protection	• PPE			• PPE
Post-Event							

Table 2-3 Control Hierarchies over Time Showing Their Alignment with ‘Common’ Approach shown in Column One (Table 1 of 3)

Focus of Control	Wigglesworth 1972	Haddon 1973	Johnson 1973	NIOSH 1973	Bird & Loftus 1976b	Hammer 1976
Source Reduction	• Remove Hazard	• Remove Energy • Reduce Energy	• Limit Energy • Prevent Energy Buildup	• Substitution	• Eliminate/Substitute Energy • Reduce Energy	• Eliminate Hazard • Reduce Hazard
Containment	• Control Hazard	• Prevent Energy Release • Modify Energy Release	• Prevent Release • Slow Release	• Isolation	• Energy Barrier	• Engineering, Fail-safe Designs, Monitoring, • Failure Minimisation
Separation		• Separation • Barrier • Modify Contact Surface	• Source Barrier • Barrier Between Source and Man	• Ventilation	• Modify Contact Surfaces	
Behaviour & Worker Protection	• PPE • Education & Training	• Strengthen Recipient	• Barrier on Man • Strengthen Recipient	• Education	• Strengthen Target	
Post-Event		• Emergency Control • Rehabilitation & Stabilization	• Treat/Repair • Rehabilitation			• Emergency procedures

Table 2-4 Control Hierarchies over Time Showing Their Alignment with ‘Common’ Approach shown in Column One (Table 2 of 3)

Focus of Control	Viner 1982	Gallagher 1991	Stephenson 1991	Harms-Ringdahl 1993	HSE 1993	MacCollum 1994
Source Reduction	• Hazard/Energy Reduction	• Eliminate Hazard/ Risk	• Eliminate Energy • Limit Energy Accumulation	• Eliminate • Reduce • Safer Alternative	• Eliminate/ • Substitute	• Eliminate Hazard
Containment	• Hazard Control	• Technology	• Prevent Energy Release • Energy Barriers	• Prevent Build-up/ Release • Controlled Reduction	• Engineering at Source	
Separation	• Modify Energy Transfer		• Change Energy Release Pattern	• Separate in Space / Time • Barriers on Energy		• Guarding
Behaviour & Worker Protection	• Strengthen Recipient	• Training & Warnings • PPE	• Strengthen Targets	• PPE	• Work Systems • PPE	• Training & Warnings • PPE
Post-Event			• Treat Harm	• Damage Control		

Table 2-5 Control Hierarchies over Time Showing Their Alignment with 'Common' Approach shown in Column One (Table 3 of 3)

2.2.2 Defining the Hazard Source: Energy Barrier Models

As discussed above, the hierarchy of control owes its history to the studies of occupational hygiene. Often in occupational disease the source of the problem, a contaminant of some kind, was easy to conceptualise. The broadening of the hierarchy into the field of accident prevention was stifled because the source of the injury was unclear. The notion of unsafe acts and unsafe conditions made application of the hierarchy concept difficult as the classification according to these terms is largely arbitrary. As an alternative way of thinking, many of the hierarchies mentioned above refer to eliminating *energy* as the priority. Since the 1960's there has also been growing interest in modelling the hazard source as a source of energy. The descriptions of the injury process based on the energy principle by Gibson (1961) and Haddon (1963) are markers in this development.

> *...injuries to a living organism can be produced only by some energy interchange. (Gibson 1961, p. 79)*

> *...all injuries are causally in one of two groups, either, 'interference with whole body or local energy exchange' or 'delivery to the body of amounts of energy in excess of the corresponding local or whole body injury thresholds. (Haddon 1963, p. 636)*

These definitions made application of the hierarchy concept somewhat easier as hazards could be thought of in terms of a physical energy. The hygiene model of *hazard source* ➔ *pathway* ➔ *receiver* could be neatly applied to the study of injury. Haddon applied the concept of energy damage to the hierarchical based model of prevention and developed the following version of the hierarchy of control.

1. Prevent marshalling of energy
2. Prevent or modify the release of energy
3. Remove the man from the vicinity of the energy
4. Impose a barrier

(Haddon 1963)

The energy approach to accident analysis has since been popularised particularly by Johnson (1973; 1980) in the text, *The Management Oversight and Risk Tree* (MORT).

Johnson (1973) embedded the energy transfer concept within the accident analysis and risk modelling of the MORT tool, a technique developed for the US Atomic Energy Commission. He defined an accident in the following way.

> *The accident definition which evolves is:*
>
> 1. *An unwanted transfer of energy,*
> 2. *Because of lack of barriers and/or controls,*
> 3. *Producing injury to persons, property or process,*
> 4. *Preceded by sequences of planning and operational errors, which:*
>
> *a. Failed to adjust to changes in physical or human factors,*
>
> *b. And produced unsafe conditions and /or unsafe acts,*
>
> 5. *Arising out of the risk in an activity,*
> 6. *And interrupting or degrading the activity. (Johnson 1973, p. 25, original emphasis)*

Johnson reinforced the *energy barrier* idea as a way of conceptualising methods of accident prevention, and introduced the *energy trace* as a method of system and accident analysis. The model emphasised the identification of energy sources by way of energy trace analysis and energy barrier analysis. Johnson's use of energy trace has since been cited by many authors in the area of safety (for example; Rahimi 1986; Ferry 1990; Stephenson 1991; Harms-Ringdahl 1993; Vincoli 1993). The process of injury and also the definition of hazard has often expressed in terms of energy.

> *Control and guard all energy, and the environment will be right for people to work safely. (Aitken 1973, p. 7)*

> *Accident: An unwanted energy transfer (an incident) causing property damage and/or human injury. (Energy Research and Development Administration 1977, p. vi)*

> *In abstract terms we should only consider the results of damaging energy exchange and provide countermeasures, preferably passive, to control the magnitude of this.*
> *(Emerson 1985, p. 25)*

> *Let us begin by defining "accident" as an event involving an unwanted transfer of energy. Energy produces injury and damage unless there are adequate controls or barriers.*
> *(Ferry 1990, p. 239)*

An accident is defined as occurring when this unwanted flow of energy, in the absence of adequate barriers, strikes targets in the energy path and injures people and/or damages property. (Stephenson 1991, p. 147)

...an incident is defined as an unwanted flow of energy resulting from inadequate barriers or having failure without consequence. An accident is further defined as an unwanted flow of energy or an environmental condition that results in adverse consequences. (Vincoli 1993, p. 101)

Hazard—a source of potentially damaging energy or a situation that may give rise to personal injury or disease. (Standards Australia 1996, p. 9)

Thus the energy terminology has become reasonably common in the descriptions of the accident/injury process. Similarly the defintion of hazard as the source in the pictorial model of the *hazard source* ➔ *pathway* ➔ *receiver* model been outlined by several writers (for example; Figure 2-8; Figure 2-9; Figure 2-10).

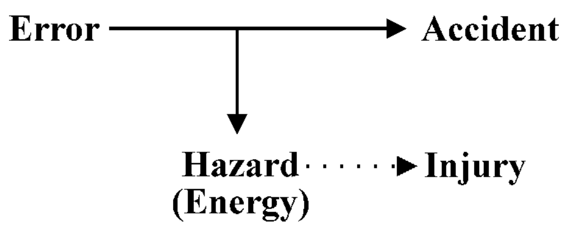


Figure 2-8 Injury Causation Model (Adapted from Wigglesworth 1972)

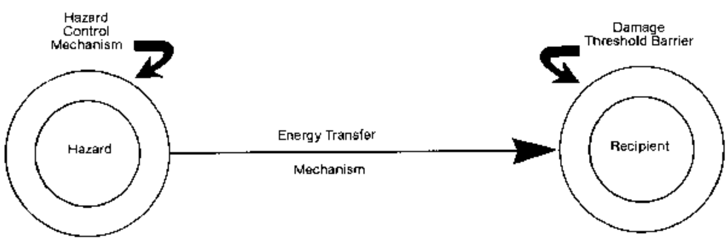


Figure 2-9 Extended Energy Damage Model (Viner 1982)

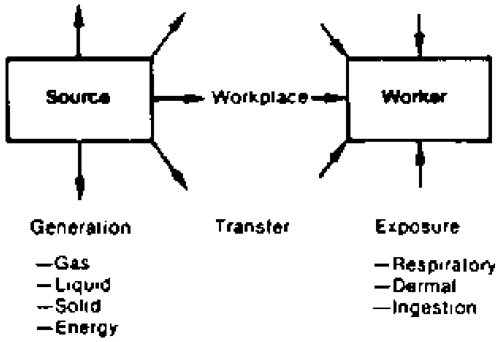


Figure 2-10 Generalized Occupational Exposure
(Office of Technology Assessment 1985)

An injury was thought to result from an escape or loss of control of a hazard, transfer of this energy to a recipient, and lastly injury to the recipient. The modelling in this way provided a sense of scientific rigour in contrast to the subjectivity of the unsafe act / unsafe condition model. The Energy Research and Development Administration (1977) outlined the following process for the systematic assessment of risk.

1. *All energy sources must be controlled*
2. *All potential targets of uncontrolled energy release must be identified for each energy source.*
3. *All control mechanisms and barriers to energy release must be identified for each energy source.*
4. *An analysis must be performed in each case to determine failure modes and effects, in order to identify the residual risks. (ERDA 1977, p. 3)*

While Kjellén and Sklet (1995) point out that the use of energy analysis can bias hazard identification toward accidents with large consequences and well-defined energy sources, they recognised that the methodology is a useful broad identification tool especially given the clear link to hazard controls.

There is now considerable support for energy damage as fundamental to the study of accidents and injury. In general, the process of injury has been described as beginning with the existence of an amount of energy that could cause harm, hence the term; *potentially damaging energy* (for example; Waller & Klein 1973; Wigglesworth 1984; Viner 1991). An accident then consisted of a release or *loss of control* of this energy

(Aitken 1973; Hoyos & Zimolong 1988; Viner 1991). The loss of control of potentially damaging energy, *may* then lead to injury via a transfer, or exchange of energy with humans (Gibson 1961; Haddon 1963; Bird & Loftus 1976b; McFarland 1973; Viner 1982; 1991; Wigglesworth 1984; Waller 1987; Ferry 1988; Thygerson 1992; Harms-Ringdahl 1993; Vincoli 1993). This separated the notion of the accident, or damaging energy release, and the interaction of that energy with humans. The exchange of energy, however, does not automatically imply injury, as many authors have pointed out, the exchange of energy only results in injury if it exceeds the human threshold of energy exchange (Gibson 1961; Haddon 1963; McFarland 1973; Viner 1982; 1991; Wigglesworth 1984; Emerson 1985; Ferry 1988) or interferes with whole body energy systems, as in the case of suffocation (Haddon 1963; Bird & Loftus 1976b; Wigglesworth 1984).

In summary the overall valuable points taken from the energy damage models are that they;

1. Show the process (*energy source* ➔ *pathway* ➔ *receiver*).
2. Highlight ways to manage the process (energy controls, path controls, PPE)
3. Highlight the problem source rather than the person.

2.2.3 Ergonomics and the Study of Work

> *Ergonomics is a science which developed from the need to understand the physiological, psychological and social needs of operators during the process of designing work environments. ... The word ergonomics, first used in 1949, is derived from two Greek words, ergon meaning work, and nomos meaning natural laws. Thus, ergonomics means the natural laws relating to work. (Standards Australia SAA HB59—1994, p. 5)*

Ergonomics, or human factors, is the study of the interaction of people, with their surroundings and equipment. The importance of considering the capabilities of people in design is emphasised by many regulatory documents such as the Swedish *Work Environment Act* and the New South Wales *Occupational Health and Safety Act.*

> *Working conditions shall be adapted to people's differing physical and mental aptitudes. (Work Environment Act 1994 (original 1977) (Sweden) ch.2.s.1)*

> *The objects of this Act are: to promote an occupational environment for persons at work which is adapted to their physiological and psychological needs*
> *(Occupational Health and Safety Act 1983 (NSW) s.5.(1)(c))*

Fashioning tools to human needs is age old, however in terms of the scientific application of ergonomics to work methods, the work of Taylor (1911) and Gilbreth (1911) are significant markers. Taylor and Gilbreth were primarily interested in the improvement of manual work, probably because that was the main type of work at the time.

Taylor began work as a labourer and developed an interest in work methods while working in a steel company in the late 1800's. The terms *Scientific Management*, *Taylorism*, and *Time Study* resulted from Taylor's development of systematic work analysis, improvement and organisation. As a management model, *Taylorism* now seems to be out of favour and discussion of why this is so might be interesting but probably belongs elsewhere. The relevant aspect of Taylor's work are the studies of manual handling. Although he didn't use physiological terms like *static muscle work*, his investigations centred on this type of theory. Much of Taylor's early work was about manual work efficiency. Aside from an over-emphasis on the selection of workers, Taylor embodied the principles of ergonomics with the attention he gave to matching work to the physical capabilities of humans. Taylor also worked in non-manual handling areas such as the study of efficient metal machining.

Gilbreth (1911), whose work became known as *Motion Study*, also aimed toward the improvement of manual work productivity. Gilbreth showed that improvements in the motions of work could be vastly improved; often many movements could be eliminated. Gilbreth's writing embodied the ergonomic model more clearly than Taylor's. The improvement of work according to Gilbreth involved considering;

1. the worker;
2. the surroundings, equipment, and tools; and
3. the motions.

> *A careful study of the anatomy of the worker will enable one to adapt his work, surroundings, equipment, and tools to him. (Gilbreth 1911, p. 10)*

For example; the improvement of bricklaying involved modifying the trowel, raising the height of the mortar box, raising the height of the brick tray, developing a brick stacking and delivery system so that the bricks were the right way round, and so on. Gilbreth employed the now popular notion of *best practice* to describe the first step in motion study.

> *There are three stages to this study:*
> 1. *Discovering and classifying the **best practice**.*
> 2. *Deducing the laws.*
> 3. *Applying the laws to standardize practice, either for the purpose of increasing output or decreasing hours or labor, or both. (Gilbreth 1911, p. v., emphasis added)*

In summary, while Taylor's name might be out of vogue by association with a management style of the past, Taylor and Gilbreth made important contributions by showing how improvements were possible by considering the human-equipment-environment relationship. They drew attention to the possibility of improving work though understanding human abilities and designing the environment and tools to suit.

Later, during World War II, ergonomics as a discipline was formalised when it became recognised that psychology had an important role in engineering design. Psychologists assisted engineers in the design of miliary equipment to improve operations such as gun, radar and aircraft control (Stevens 1946; Fitts 1947; Kappauf 1947; Taylor 1947; Chapanis, Garner & Morgan 1949). One of the simplest examples was the redesign of aircraft insignia to distinguish US aircraft from Japanese aircraft to reduce the incidence of incorrect anti-aircraft fire. Similarly, McFarland and Moore (1961) pointed out the gains to be made using ergonomics in the design of aircraft controls.

> ***Confusion has arisen when the controls for operating the flaps and landing gear are located too close together or reversed in some planes.*** *In one 22-month period during World-War II inattentive manipulation or mistaken identity caused 547 accidents in one of the services. (McFarland & Moore 1961, p. 36, emphasis added)*

The emphasis for the role of psychology was changed from one of trying to change the person to fit the job, or maybe even select a suitable person for the job, to one of providing assistance to engineers to integrate human factors into the design.

> *The designing of all forms of equipment is generally considered to be a purely engineering function. But most of the tremendous variety of articles designed by engineers, be they industrial machinery, household appliances or children's toys, are intended for use or operation by human beings. It is apparent that the utility or success of such equipment must be, at least in part, dependent upon the degree to which it is* ***suited to the psychological characteristics of the human beings*** *who must use it. (Fitts 1947, p. 93, emphasis added)*

The main message arising from the study of psychology in the military was '*...the art or gearing machines to the minds and muscles of men...*' (Stevens 1946, p. 390). Aside from Taylor and Gilbreth's work, designing for humans represented a reversal of approach. For instance in 1932, Viteles devoted around 200 pages of the text *Industrial*

Psychology, to a section headed *Fitting the Worker to the Job*; the very anti-thesis of modern ergonomics.

The fitting of people to tasks required an understanding of physiology and psychology. A great deal of psychological data about equipment controls was collected during the war, while long before this time Galton (1889) collected and collated some of the first anthropometric data such as weight, height, strength, arm span, and so on.

From the military studies the concept of the person-machine, or ergonomic system was created. The experience gained in the wartime studies lead researchers of that time to develop the ideas into pictorial information-flow models (Figure 2-11). Birmingham and Taylor's (1961) model presented in 1954 showed the role that people play in the operation of machinery in monitoring and controlling the machine. Later, Taylor (1957) and Grandjean (1982, original 1963), Meister (1971) and Singleton (1972) simplified the model by including diagrams to better illustrate the flow of information.

Chapanis (1965), and more recently Hammond (1978) went beyond the man-machine interface to include the environment factor, however their models indicated that the main interaction is between the person and the equipment. The working environment seemed to have a passive influence. Sometimes it seems convenient to include the environment as something that must be part of the interaction. For instance, in the road system, it's probably more convenient to think of road signs as environmental features rather than equipment features. McCormick (1970, p. 5) indicated that the model of ergonomics should emphasise interaction with the environment, and so should be known as; *'...man-machine-environment systems, since we shall be primarily concerned with systems that are a combination of people and machines and the environments in which they function'*. Thus the three factors of person, equipment and environment are now often represented to show the interaction between these three elements (Kuhlmann 1986; Figure 2-11).

Ergonomic System Models

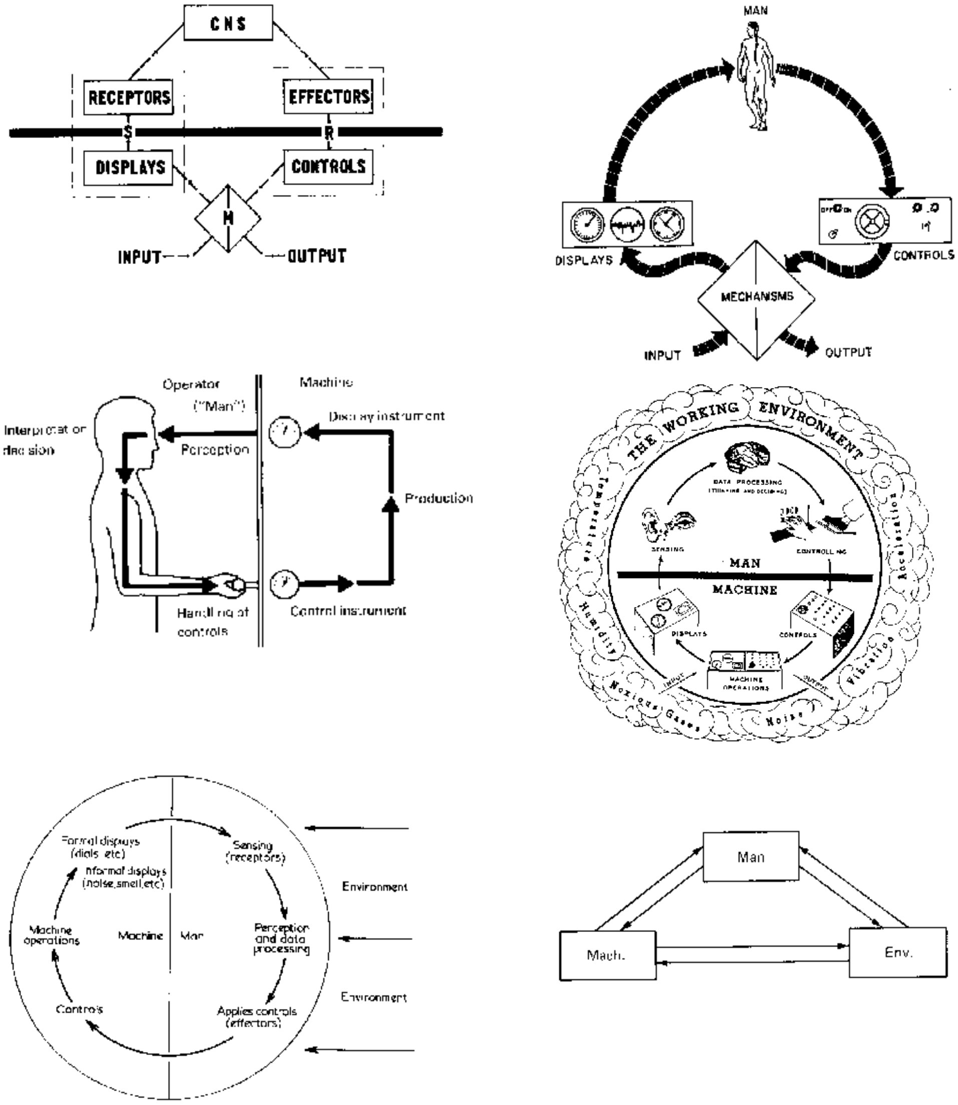
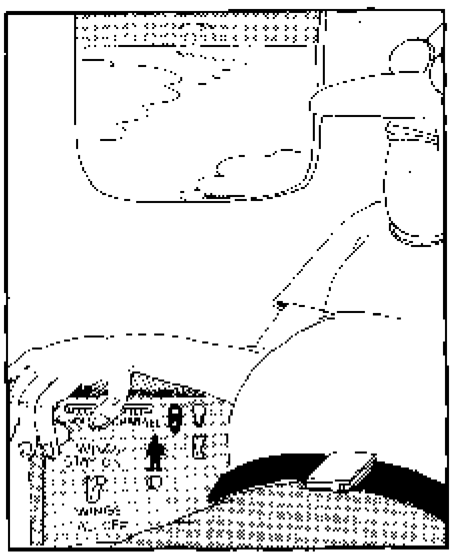


Figure 2-11 Ergonomic System Models
Clockwise from Top Left: Birmingham & Taylor (1961, original 1954); Taylor (1957); Chapanis (1965); Kuhlmann (1986); Hammond (1978); (Grandjean 1982, original 1963)

In summary, the study of ergonomics has shown the importance of the interaction of system elements. It is not only good human skills, good equipment, and good environment conditions or systems that are important for good design, it is the quality of the interaction between these elements. Furthermore it is recognised that the most reliably adapted components are the environment and equipment. The essence of ergonomics is *'...fitting a job to a man'* (Kappauf 1947, p. 85), or nowadays perhaps; *fitting the job to the person*. This represents a different way of approaching the study of hazard control compared with the unsafe acts/unsafe conditions model. Finally, Gary Larson captured the importance of good ergonomic design (Figure 2-12).



Fumbling for his recline button,
Ted unwittingly instigates a disaster.

Figure 2-12 How Poor Design Contributes to Human Error (Larson 1992)

2.2.4 Safe Place: Consolidated Concepts

2.2.4.1 A Commonality of Approach

The concept of a hierarchy of control is now common and bears a strong relationship to the control-at-source models, emphasising elimination of the hazard, or passive hazard control, as a preference over measures relying on appropriate hazard-avoidance behaviour.

Identifying the hazard source is obviously important when using the hierarchy. In occupational hygiene the hazard has often been easy to conceptualise, however in the area of injury it has not been so clear. Nowadays the definition of hazard seems to fall into two main categories; the *potential* to cause injury or illness and the *energy*-based definitions. Whether the hazard is defined in terms of the energy approach or some other way, the main intention of control at source is made clear by the hierarchical approach.

Table 2-3, Table 2-4 and Table 2-5 (pp. 57-59) show the relationship between the hierarchies and the following model.

1. Modifying the hazard source
2. Containing the hazard source
3. Separating the hazard from the person
4. Relying on personal protection and behaviour
5. Post-event measures

While categorising a particular type of control is difficult, the agreement about a general approach to prevention is evident. The ideal safe place control is complete elimination. In contrast low-order controls are often known as *safe person* controls; that is; the person is encouraged to be safe in a poor environment. In summary, the United States Congress, Office of Technology Assessment (1985) said that *'Put simply, the principle of the hierarchy of controls is to control the hazard as close to the source as possible'.*

2.2.4.2 Integrating Ergonomics and the Hazard, Path, Receiver Model

The hierarchy of control is very much a result of the linear *source* ➔ *pathway* ➔ *receiver* model. Similarly the ergonomic approach has been a significant influence in the development of the understanding of reliable ways of preventing accidents. It seems then logical to combine these two models.

In the model of *source* ➔ *pathway* ➔ *receiver*, a symbol is sometimes drawn around the hazard source to indicate the means of hazard control. If the control is to be reliable then it must employ the ergonomic methodology. Wigglesworth's (1972) model (Figure 2-8) showed how the concept of *human error* related to the common linear model and went some way to integrating some of the ergonomic methodology.

Later, Kjellén and Larsson (1981) described the energy damage process as consisting of the *initiatory*, *concluding* and *injury* phase. These three elements were thought to occur against a background of a system that could contribute to accidents by way of deviations in; material; labour; information; man/machine system; intersecting or parallel activities; and the surrounding environment. Their modelling therefore emphasised the role of ergonomics in building a safe system in order to maintain hazard (energy) control.

Taken a step further, the classic person-equipment-environment ergonomic model can be combined with the traditional *hazard source* ➔ *pathway* ➔ *receiver* model to show more clearly the relationship of the ergonomic elements in the action of control (Figure 2-13).

The model shows the ergonomic relationship between people, equipment and the environment that contributes to hazard control systems, while showing that these elements also represent the exposures to the hazard. The hazard in this model could be described as a potentially damaging energy or in general terms such as the *potential to cause harm.*

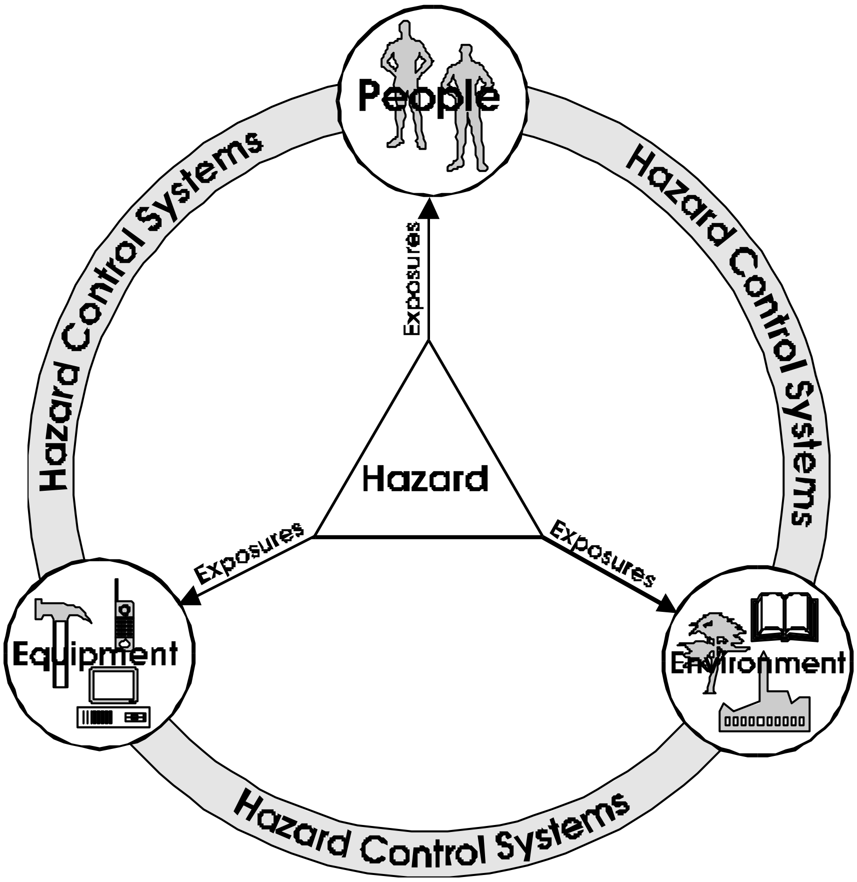


Figure 2-13 Ergonomic Hazard Management

While the linear models could be seen to give equal emphasis to the importance of controls at the person and controls at the hazard, this model centralises the issue of the hazard. The importance of control at source is therefore made more apparent. Furthermore this model shows that damage as a result of an accident can be to people, equipment, or to the environment. The environment is intended to mean the physical and organisational working environments as well as the natural environment which may also be at risk of exposure. The model shows that hazard management is dependent on the relationships between the human elements, equipment and environment features.

Methodologies for minimising risk then follow the familiar hierarchy of control; minimising the hazard source; minimising the exposures and maximising the integrity of the hazard control system (considering the role of human, equipment & environment factors).

2.2.4.3 Intrinsic Safety, Passive Safety, and the Two-Dimensional Hierarchy

Passive safety measures ... do not require anything of the person; they do not depend on human memory or constant human care. (Kalin 1994, p. 25)

The top-order hierarchy of control measures revolve around the concept of making a safe environment. These *safe place* strategies are seen by many as the most effective form of accident prevention and their success depends on two factors; the degree of reduction of exposure to the hazard source, and the degree to which control over the hazard source is passive, ergonomic, and intrinsically safe. Intrinsic safe design, or passive countermeasures, do not rely heavily on active involvement or the continuous attention of potential victims for safety. The case for the importance of passive safety has been argued in the areas of automobile safety (Nader 1965), occupational health and safety (The Committee on Safety and Health at Work 1970), and public health (Wigglesworth 1978).

The seat belt should have been introduced in the twenties and rendered obsolete by the early fifties, for it is only the first step toward a more rational passenger restraint system which modern technology could develop and perfect for mass production. Such a system ideally would not rely on the active participation of the passenger to take effect; it would be the superior passive safety design which would come into use only when needed, and without active participation of the occupant. ... Protection like this could be achieved by a kind of inflatable air bag restraint which would be actuated to envelop a passenger before a crash. Such a system has been recently experimented with for airplane passenger protection. Both General Motors and Ford did work on a system like this about 1958 but dropped the inquiry and now refuse even to communicate with outside scientists and engineers interested in this approach to injury prevention. There are a number of general energy-absorption systems that engineering ingenuity could devise to operate whether inside or outside the vehicle.
(Nader 1965, p. 124)

...the first step in the promotion of safety and health at work is to ensure, so far as may be practicable, that plant, machinery, equipment and materials are so designed and constructed as to be ***intrinsically*** *safe in use.*
(The Committee on Safety and Health at Work 1970, p. 111, emphasis added)

The consensus that passive countermeasures (i.e., those that are independent of human behaviour) are more likely to be successful than those that are active (i.e., those that require some component of human behaviour for their success) follows a basic principle of public health in that countermeasures apply to persons at risk without their active involvement. (Wigglesworth 1978, p. 793).

If the minimisation of risk is by a combination of hazard exposure and the creation of an intrinsically safe, passive, or ergonomic hazard control, then the hierarchy can be thought of as a two-dimensional construct. Within this one could argue that the minimisation of hazards and the minimisation of exposure represents two variables. However by eliminating the hazard so too do we effectively eliminate exposure to that hazard. Likewise by eliminating exposure we effectively eliminate the possible impact of the hazard. Conceptually, *exposure* can be considered to represent a unit *person*, being exposed at unit proximity to a unit hazard. We can say then that the safe place concept is composed not of a one dimensional variable along the continuum of controlling the problem at the source to controlling it at the person, but a two dimensional variable. The two dimensions are those of exposure and that of integrity of control (ergonomics).

Stephenson (1991) referred to a draft US Army document *Facility System Safety Manual*, that modelled risk controls in a matrix format (Table 2-6).

	Hazard Control Mechanism			
Hazard Control	*I. Design*	*II. Passive Safety Device*	*III. Active Safety Device*	*IV. Warning Device*
A. Eliminate Energy Source	1	1	2	3
B. Limit Energy Accumulated	1	1	2	3
C. Prevent Release	1	2	2	3
D. Provide Barriers	2	2	3	4
E. Change Release Patterns	2	3	4	4
F. Minimize/Treat Harm	3	3	4	4

Table 2-6 Control Rating Code (CRC) Matrix (from US Army *Facility System Safety Manual* in Stephenson 1991)

A score of one indicated the best control (for example eliminating the energy source through design) while a score of four indicated the least desirable control (for example minimising or treating damage through a behavioural mode of action). This matrix showed the two dimensional nature of the hierarchy of control. This concept can be perhaps more effectively represented by the following model (Figure 2-14).

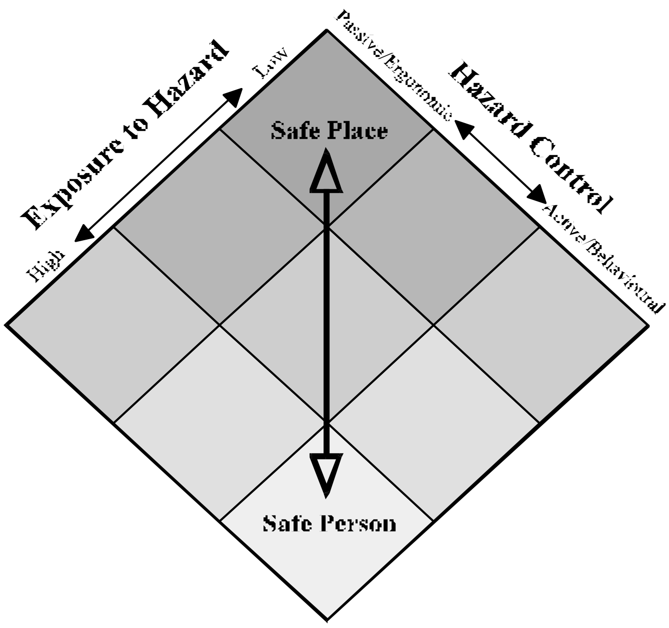


Figure 2-14 Safe Place Matrix

The Safe Place Matrix (Figure 2-14) represents the relationship between safe place and safe person control measures in terms of hazard reduction and control. The link between safe place and safe person is a continuum based on the following.

1. A reduction in hazard exposure (by hazard reduction or exposure reduction).
2. Improvements to the ergonomics of the hazard control (enhancing passive control).

An ideal safe place control is one that eliminates the hazard and maintains this elimination by passive means, whereas a safe person control is one that leaves the hazard in place and control the hazard by way of active involvement of people (normally the potential victims). The banding on the model indicates levels within the safe place to safe person continuum.

2.2.4.4 The Hierarchy: A Problem Solving Tool

Leading to the discussion in the following chapter (creative thinking), one would hope that the hierarchy of control serves as a productive thinking tool. Whether employing the common one-dimensional list-based hierarchy or the two-dimensional construct suggested above, one would hope that the outcome would be better solutions. The hierarchy ideally plays an active role, guiding the thinking first toward the higher order controls. This is important in that the hierarchy should assist the development of good solutions.

Alternatively the hierarchy can be used to classify one solution against another. In this way the system is simply a set of boxes to put controls in after they've been developed. This may have some advantage in comparing the controls but the disadvantage of using the hierarchy in this way is that there is potential to become very confused as it often seems that one solution belongs in many categories.

The relationship between the hierarchy of control and the methodologies for creative thinking are very strong. A key to creative thinking is to escape from assumptions that have become dominant though experience. The hierarchy of control is a specific application of these techniques to accident prevention. By its nature the first step of eliminating the hazard is a challenge to the current situation; it implies that some hazard put in place probably for some very justifiable reason should be eliminated. As Laflamme (1990) noted, the important features of accident models is that they direct preventative thinking toward *transforming* the system (*macroscopic* thinking) rather than focussing on microscopic issues with the current system such as the behaviour of people.

> *In fact, prevention could find its source in the man-machine system, at a microscopic level, but also in eventual corrections and transformations of the general conditions prevailing in the workplace. (Laflamme 1990, p. 159)*

Stepping back from the microscopic level of analysis and considering workplace *transformations* implies an approach sought when encouraging a creative style of thinking. The parallels to creative thinking are thus very strong. The main links are that the hierarchy provides a challenge to current assumptions and that the hierarchy's key function is to act as a thinking directing tool, positively affecting the outcome.

2.3 Accident Prevention Summary

From early this century, accidents have been seen mainly to be a result of either unsafe acts or unsafe conditions. This way of thinking was an extension of the dichotomy of machinery and non-machinery accidents that was a relevant way of thinking about accidents in the industrial revolution of the nineteenth century.

From a premise that accidents were the result of either unsafe acts or unsafe conditions, the work of Heinrich in the 1930's embedded a psyche that the primary cause of accidents were the unsafe acts of people. In popular culture and in many scientific circles, this model continues to be accepted and promoted. However popular the model remains, there is a growing core of opinion that the unsafe acts and unsafe conditions model has little validity, is easily manipulated, and unfortunately has the tendency to lead to ineffective accident prevention measures.

Any accident can be explained as due to *either* unsafe acts or unsafe conditions; thus the attribution to one or the other is largely arbitrary and depends on the investigator's bias. The investigator is likely to be affected by a general belief about the pre-eminent role of people in accident causation; thus the model becomes self perpetuating. The model invariably assigns the cause of accidents the bad behaviour of people (often victims) and therefore typical prevention measures aim at altering the attitude and behaviour of people.

Escaping from this trap demands a new model. The unsafe acts and unsafe conditions model is widely criticised due to the imprecision involved in making a decision between these two options. Given the difficulty of assigning a cause of an accident as either an unsafe act or unsafe condition, this way of thinking would seem to be of little use.

Legislation now universally adopts the model of focussing on the hazard source. Rather than identifying unsafe acts and unsafe conditions, these laws require a focus on hazards. The hazard source concept is one that arises most directly from the study of occupational diseases. Often the source of the problem was readily identified as a contaminant (such as an airborne chemical or dust). The study of occupational diseases was then modelled as being composed of *hazard source* ➔ *pathway* ➔ *receiver*. The priority for effective prevention was then control at source.

The now familiar hierarchy of control model emerged from this way of thinking and eventually became a standard methodology for understanding accidents and prevention. A useful concept that facilitated the application the model to the study of traumatic injuries was the defintion of energy sources as the primary source of hazard. This conceptualisation has now become reasonably popular and has provided a more rigorous approach to the analysis of risk. However the energy-based approaches are not universally used, hazards often being defined simply, as the *potential to do harm*, or similar. There is yet to be a fix on a standard set of definitions, although the model of *hazard source* ➔ *pathway* ➔ *receiver* is established.

The safe place concept revolves around two main themes. Firstly the reduction of exposure to a hazard. Exposure to the hazard takes in the concept of the hazard itself and the exposed groups; thus the exposure can be reduced by focussing on either element; by reduction or substitution of the hazard itself or by rearranging the way work is done so that the groups at risk are exposed to a lesser degree. The second concept is that of control over the hazard and how the integrity of the system is maintained. The core concept here is that of the primacy of passive controls; those controls that place little reliance on human vigilance for its success. Achieving these controls implies a good understanding of ergonomics in design. In summary then the following points describe the models of thinking that would be important in engineer's application of contemporary approach to the prevention of injury.

- Accidents are plannable, predictable and controllable.
- Accidents are best prevented by the safe place approach.
- The hierarchy of control is a tool to guide hazard controls toward safe place controls.
- The hierarchy of control is a list of general control ideas ranging from controls that focus on the hazard source to controls that focus on those people at risk.

- The hierarchy of control draws its beginnings from the study of occupational hygiene where the *hazard source* ➔ *pathway* ➔ *receiver* model was employed.
- The *hazard source* ➔ *pathway* ➔ *receiver* was generalised to the problem of injures especially through the energy approach.
- The hierarchy of control can be conceptualised as a two-dimensional construct composed of the minimisation of exposure and the maximisation of the integrity of the control considering the ergonomics of that mechanism.
- The hierarchy of control is a problem-solving methodology that shares strong parallels with general creative thinking tools.
- The hierarchy of control encourages a re-examination of the current work system.
- The same solution can be suggested more than one in the hierarchy of control as the hierarchy is for the development of solutions rather than their categorisation.
- The development of multiple solutions allows a greater choice of action and also may be important given the potential for the staged implementation of controls.

Chapter Three

Creative Thinking

3. Creative Thinking

3.1 Creative Moments

Create:

1. *to bring in to being; cause to exist; produce*
2. *to evolve from one's own thought or imagination*
3. *to be the first to represent (a part or role)*
4. *to make by investing with new character or functions; constitute; appoint*
5. *to be the cause or occasion of; give rise to*
6. *to be engaged, often ostentatiously, in creating something, as a work of art.*

(The Macquarie Dictionary 1985)

There are many well-known stories describing great moments of things coming into *being* in the midst of *original thought* and *imagination*.

Archimedes is said to have leapt from the public bath and run down the streets of Syracuse shouting *Eureka!*, meaning, *I've found it!* Archimedes observed that as he immersed himself in the water the level rose. Archimedes realised this would be a good way to measure the volume of metal in a complicated crown so that he could then determine if the crown was entirely gold or a mixture of gold and another metal.

Darwin's theory of selection became clear to him while relaxing reading a paper for his own entertainment about population growth.

Watt is supposed to have observed a kettle lid bouncing away under the pressure of the steam and transferred the concept to a larger system; the steam engine.

Pythagoras discovered a basic principle of physics, not in a laboratory, but when passing a blacksmith's shop and noting that rods of iron being hammered gave off varying sounds according to their length.

Alexander Fleming happened across penicillin by observing mould on a culture plate.

French mathematician, Henri Poincaré, found the concepts of mathematical functions called Fuscian functions bouncing around in his head while unable to sleep after drinking coffee and then later while taking a bus trip to the beach.

Mozart claimed that he did not know from where his musical ideas came. They appeared in his mind while daydreaming, when relaxed and in good spirits.

In 1885 Röntgen noticed by chance that a paper screen covered in barium platinocyanide became fluorescent while a cathode ray tube was operating *inside* a black cardboard box. At the time it was thought no radiation could penetrate this box. Röntgen soon discovered that these *X rays* could also penetrate human flesh and reveal an outline of the skeleton.

In 1821 Faraday invented the electric motor and made a working model, however the invention attracted little interest. Ten years later Faraday invented the dynamo which became very popular for generating electricity from steam engines. The electric motor was ignored until 1873 when a technician mistakenly connected a second dynamo to one already being driven by a steam engine. The second dynamo sprung into life and the electric motor was reborn; fifty years after its invention! In hindsight it was obvious that the motor was the reverse of the dynamo but beforehand it was not, even to the inventor!

For a century after vaccination (arising from vacca meaning cow owing to the connection with cow-pox) to immunise against small-pox became common, it had not been realised that the same principle could be applied more widely. In 1879, Pasteur was investigating chicken cholera and mistakenly left a culture aside for several months. When subsequently injecting chickens with the weakened culture they survived, and were then found them to be immune from the disease. One hundred years after its establishment as a way of preventing small-pox, Pasteur had discovered that vaccination had wider application.

3.2 Creative People

Creativity is often discussed in terms of great creative achievements such as those outlined above and it's been common to associate the creative outcome with the greatness of the person involved. Rickards (1988) argued this case suggesting that creativity is usually viewed by most people as a special skill held by special people. He described experiments where he has asked people to think of someone being creative. Upon this request, he says that the subjects rarely think of themselves. The image they have is usually that of a painter, writer, architect, or maybe a famous thinker, like Newton or da Vinci. I've done this small experiment too and found much the same result. Passmore (1991) commented that the notion of a *work of imagination*, tends to be narrow, not only implying greatness but tending to be limited to works of art or literature such as poetry to the exclusion of other fields like science or engineering. Weisberg (1986) said that it may be surprising to many that great thinkers like Newton and da Vinci once experimented with now odd notions such as the practice of alchemy and the idea of people flying by attaching feathers to their arms (although this sounds something like a modern hang-glider so maybe da Vinci has been proved correct). Seeing creativity as something other, *special*, people do is a great barrier to creativity as Ribot suggested a century ago.

> *Invention is thus unduly limited when we attribute it to great inventors only.*
> *(Ribot 1906, p. 156)*

Furthermore a person who is *creative* is often characterised as eccentric or perhaps mentally unstable (Kubie 1961; Prentky 1989). For example great thinkers like Socrates and Newton were thought to be mentally unstable (Prentky 1989). Torrance commented that this common perception has limited the wide teaching of creative thinking.

> *Doesn't everybody know that the highly creative person is "a little crazy" and that you can't help him anyway?...Unfortunately, these are attitudes which have long been held by some of our most eminent scholars and which still prevail rather widely. (Torrance 1962, p. 1)*

An analysis of abstracts of creativity research reveals a great interest in personality, giftedness, intelligence, sex, age, socio-economic status, reading skills, etcetera. Great effort has been expended testing relationships between personal factors and creativity. For instance, Furnham and Yazdanpanahi (1995) recently reported that psychotics tend to produce more *creative* ideas when brainstorming than non-psychotics. Many writers in the area of creativity have agreed with Torrance (above) and have said that the focus on personality is misleading and unfortunately guides efforts away from examining the creative process (for example; Harrisberger 1966; Perkins, 1981; Isaksen 1987b; Niemark 1987; Zaleznic 1988; Halpern 1989; Mason 1989; Barry & Rudinow 1990; Torrance 1993; Sternberg & Lubart 1996). In short, the study of creativity as it relates to the personalities of the great achievers gives little clues as to how other people can be more creative. The alternative is to consider great creative outcomes in terms of some type of process or method.

3.3 Problem-Solving Process

Formal descriptions of the problem-solving process have often followed a step-by-step model (Table 3-1). The typical steps include problem identification, information gathering, ideation, exploration, incubation, etcetera (for example; Harrisberger 1966; Gordon 1969; Bransford & Stein 1984; Zechmeister & Johnson 1992).

Problem Solving Processes		
Harrisberger (1966)	***Bransford & Stein (1984)***	***Zechmeister & Johnson (1992)***
1. Define	*1. Identify*	*1. Identify*
2. Ideation	*2. Define*	*2. Define*
3. Synthesis	*3. Explore*	*3. Set goals*
4. Optimisation	*4. Act*	*4. Alternatives*
5. Detail & development	*5. Look*	*5. Narrow alternatives*
6. Test & improve		*6. Evaluate alternatives*
		7. Decide
		8. Trial

Table 3-1 Problem Solving Models

These processes can be traced to the methods of Ribot (1906) and Wallas (1926) shown in Table 3-2. Wallas (1926) based the process on the work of Helmholtz and Poincaré.

To begin the problem solving process Poincaré emphasised preparation and then incubation.

> *These sudden inspirations ... never happen except after some days of voluntary effort which has appeared absolutely fruitless and whence nothing good seems to have come, where the way taken seems totally astray' (Poincaré 1952, p. 38)*

> *Most striking at first is this appearance of sudden illumination, a manifest sign of long, unconscious prior work. The role of this unconscious work in mathematical invention appears to me incontestable, and traces of it would be found in other cases where it is less evident. Often when one works at a hard question, nothing good is accomplished at the first attack. Then one takes a rest, longer or shorter, and sits down anew to the work. During the first half-hour, as before, nothing is found, and then all of a sudden the decisive idea presents itself to the mind. (Poincaré 1952 p. 38)*

Problem Solving Processes		
Ribot (1906) - Complete	***Ribot (1906) - Abridged***	***Wallas (1926)***
1. Idea (the aim) and Incubation	*1. General preparation (unconscious)*	*1. Preparation*
		2. Incubation
2. Invention or Discovery	*2. Idea, Inspiration, Eruption*	*3. Illumination*
3. Verification or Application	*3. Constructive and Developing period*	*4. Verification*

Table 3-2 Problem Solving Models from the Early 1900's

Incubation, like intuition, was intended to allow the brain to unconsciously sort the chaos into order. Ochse (1990, p. 243) described intuition as *'...unconsciously triggered automatic integration of relevant elements of information...'*. Because this process is apparently illogical, it is sometimes called *gut* feel, not really a function of the supposedly *logical* brain. Situations where definitions are poorly defined or information appears unclear lend themselves to this type of thinking. Following *incubation*, a further period of conscious effort was thought to give rise to *illumination*; the flash of insight about a potential solution. A period of more conscious effort was then recommended in the *verification* phase to the test the validity of the solution.

These procedures describe a metacognitive guide to attacking a problem. They systemise a way of thinking about problems. However, the attention placed on problem defintion and the assumption that the right problem can be identified at the beginning has been criticised (for example; Harrisberger 1966; Brann 1991; Csikszentmihalyi 1992). These are criticisms of the methodologies in their totality and are valid, but here I intend to focus on the core; the creative event; the *breaking of conceptual boundaries*.

3.4 Thinking Outside the Boundaries

Great creative efforts seemed to be characterised by changes in paradigms. The pivotal events have been those that changed the domain of the potential solution. The key element to the creative process seems to be some insightful thinking that forms a new arrangement out of old information. Guilford (1950), a guiding influence over creativity research, stressed the importance of *transformations*; the *change of paradigms* as the key process, and employed the term *divergent thinking* to describe this way of thinking. The change of paradigm, or divergent thinking, is characterised by the *nine dot* task (Figure 3-1). The task is to connect the dots with a continuous line of no more than four straight sections.

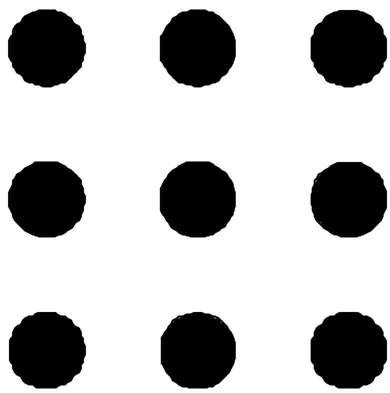


Figure 3-1 The Nine Dot Task

The classic solution requires moving outside an assumption that the lines need to be within the boundaries of the *square* (Figure 3-2). Part of solving the nine dot problem is breaking the assumed boundary. This is the pivot to solving the problem.

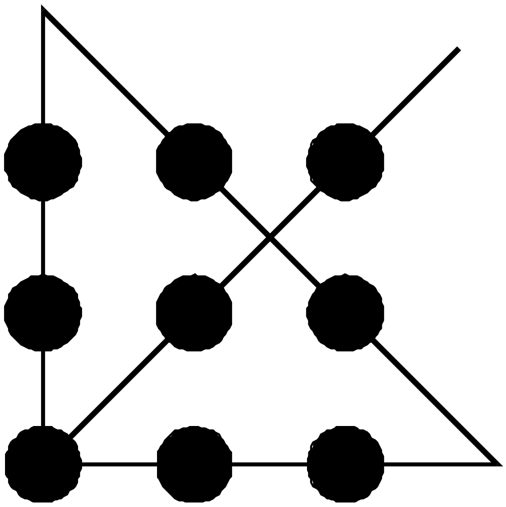


Figure 3-2 The Classic Nine Dot Solution

The insightful model of creative thinking was discussed early this century and many of the concepts considered at that time remain current. Wallas (1926), like others, discussed *illumination* but did not speculate on how illumination can be encouraged; other than to be prepared. In the text *Creative Mind*, Spearman suggested that new ideas could be formed by abstracting the principles of one idea into the realm of another (Figure 3-3).

> *When two or more items (percepts or ideas) are given, a person may perceive them to be in various ways related... (Spearman 1930, pp. 18) ... When any item and a relation to it are present to mind, then **the mind can generate in itself another item so related**.*
> *(Spearman 1930, p. 23, emphasis added)*

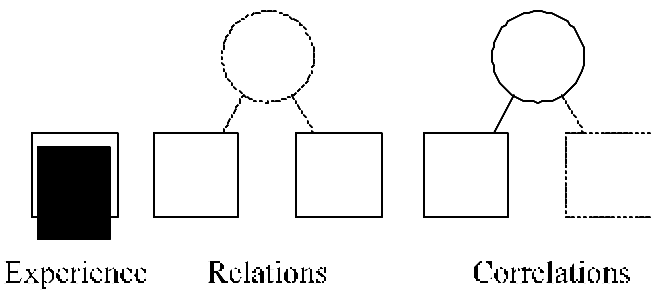


Figure 3-3 Principle of Experience, Relations and Correlations (Spearman 1930)

Like Spearman, Ribot (1906) considered creative thinking to chiefly involve association, and especially analogy; a form of association involving association by resemblance.

> *Analogy, an unstable process, undulating and multiform, gives rise to the most unforeseen and novel groupings. Through its pliability, which is almost unlimited,* ***it produces in equal measure absurd comparisons and very original inventions****.*
> *(Ribot 1906, p. 27, emphasis added)*

Spearman and Ribot emphasised the abstraction of ideas from one domain to another. Later, Hebb (1949) commented that a feature of creative thinkers is a willingness to borrow ideas from another field; a willingness to connect the apparently unconnected.

> *It is, likewise, a basic factor in originality, the original and creative person having, among other things, unusual sensitivity to the applicability of the already known to new problem situations. (Hebb 1949, p. 110)*

The central element of creative thinking seems to be this movement, or breaking of assumed boundaries, or dominant paradigms. However not all ascribe to the theory that creativity is characterised by insight. Ochse (1990) commented that a great deal of unremarkable work normally accompanies great achievements. Burnham and Davis (1969) demonstrated this concept with some experiments using the nine-dot problem (see Appendix A for detail). They measured the success of subjects working on the nine dot problem when given various clues. While drawing outside the boundary is important to the ultimate solution, a clue to this effect facilitated only reasonable improvement. However, changing the diagram (Figure 3-4) lead to a dramatic improvement.

Similarly, Weisberg and Alba (1981) conducted a series of experiments that showed that breaking the boundary did not lead to an immediate solution (see Appendix A). From these experiments Weisberg and Alba (1981), like Burnham and Davis (1969) showed that while the clue to break the assumed boundary exposes the subjects to the domain in which the solution can be found, it does not necessarily quickly lead to the solutions itself.

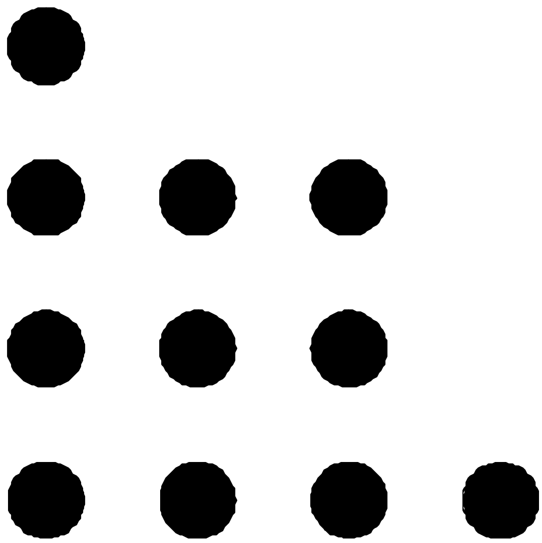


Figure 3-4 The Eleven Dot 'Nine Dot' Task
(from Burnham & Davis 1969)

Weisberg (1995) later argued that the attention given to restructuring is too high. This claim is supported by the experiments of Burnham and Davis (1969) and Weisberg and Alba (1981). Their implication was that the aim of thinking *outside the square* has been overemphasised. It would seem though that their experiments did not reject the importance of thinking outside the square, but showed that making use of a suggestion like "what about drawing outside the square", will probably require a substantial amount of subsequent work to ultimately be useful. This does not mean that the divergence to thinking outside the square is not vital to the solution. While divergent thinking does not necessarily offer quick solutions it is an important pathway to solving many problems.

De Bono (1992a) described this divergent thinking as escaping from the *boundary of reasonableness* (Figure 3-5). In the classic stories of creative achievement it seems that a fortuitous event typically triggered a new way of thinking. It seems often the boundary of reasonableness has been prodded by happenstance events. Watt had a cup of tea. Fleming and Pasteur forgot to do the dishes. Darwin read a magazine. Archimedes took a bath. Mozart had a good time and a daydream. What's the message in this for the development of the type of creativity these people enjoyed? The gathering of information won't in itself necessarily inspire the creative moment. As Dewey said; '*Observation supplied the near, imagination the remote*' (Dewey 1910, p. 223). The challenge is to arrange more of these useful events that cause a re-examination of the domain of the likely solutions.

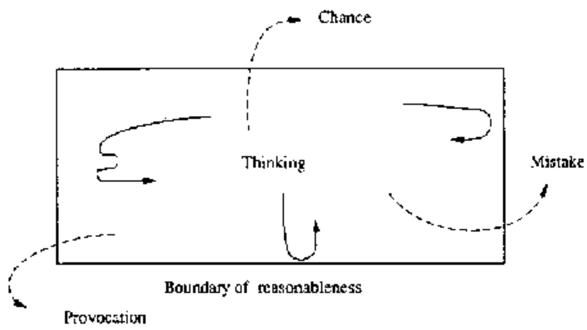


Figure 3-5 Thinking Outside the Boundaries
(de Bono 1992a)

As a demonstration of the continuous need for divergent thinking, Adams (1987) wrote that a young reader had written him a letter explaining that he had solved the nine-dot problem with one-line line. Adams' correspondent had broken normal assumptions about the thickness of lines relative to the dots and had used one really thick line! However, while the elegance of this new solution is obvious, there are widely discussed reasons why insights such as these are unlikely to occur.

3.5 Thinking *Inside* the Boundaries: Uncreative Mind

The notion of *thinking outside the boundaries* is thought to be unnatural. The mind seems more adept at repetition rather than the creation and this theory that basic function of the mind impedes creative thinking is now widespread (for example Gerard 1952; de Bono 1969; Gardner 1982; Adams 1987; Rickards 1988; Kosko 1993).

The way the mind is suited to repetition and the relationship of this to creative thinking is widely mentioned now, but was also apparent in the writings of Locke (c. 1680), Hume (c.1740) and early this century, such as Dewey (1910), Köhler (1930), and Spearman (1930). Drawing from the ancient Greek principles, Hume for instance referred to the principle of *custom*, and suggested that repetitive experience of the association of ideas tends to infer a similar association in the future, even when this may not exist. Locke suggested that given the tendency toward self-organisation of information, that the gathering of information was not thinking or learning. Learning was facilitated by the independent *reorganisation* of the information; or a *transformational* approach, to use Guilford's (1967) terminology. The gathering of information then is preparatory but clearly not central and can play a negative role by reinforcing invalid ideas. Both Locke and Hume considered that familiarity represented an impediment to creative thinking.

> *Let a man be given up to the contemplation of one sort of knowledge, and that will become everything. The mind will take such a tincture from a familiarity with that object, that everything else, how remote soever, will be brought under the same view.*
> *(Locke 1882, p. 45, original c.1680)*

> *For wherever the repetition of any particular act or operation produces a propensity to renew the same act or operation, without being impelled by any reasoning or process of the understanding, we always say, that this propensity is the effect of Custom.*
> *(Hume 1910, p. 339, original c. 1740)*

Dewey's writings around the turn of the century similarly suggested that the self-supporting nature of most evidence was a barrier to creative thought.

> *Empirical evidence follows the grooves and ruts that custom wears...failures to agree with the usual order are slurred over, cases of successful confirmation are exaggerated.*
> *(Dewey 1910, p. 148)*

> *Experience is not a rigid and closed thing; it is vital and hence growing. When dominated by the past, by custom and routine, it is often opposed to the reasonable, the thoughtful.*
> *(Dewey 1910, p. 156)*

Ribot (1906) suggested that the brain does not record accurately but records information selectively based on experience and reinforcement. Ribot said that images stored by the brain are changed according to experience. Spearman then went further and suggested that this process is a hindrance to creative thought.

> *[The mind]... **is not at all like a photographic plate** with which one may reproduce copies indefinitely...the image undergoes change like all living substance...*
> *(Ribot 1906, p. 19, emphasis added).*

> *...the mental energy, taking the line of least resistance, is directed along those channels which have by previous usage-that is to say, by virtue of retentivity-acquired a disposition to receive it. All **such mere reproduction, or course, is the very antithesis to creation**.*
> *(Spearman 1930, p. 32, emphasis added)*

These ideas, established about a century ago, form the basis of today's understanding of the conservative nature of thinking. Patterns of experience, or memory make everyday life possible. The more familiar, the stronger the pattern. Like a river does not suddenly change it's course due to a small change in rainfall patterns, the mind does not alter patterns readily; they are moulded into shape over time.

> *We recognize but cannot define. The neural nets in our brains are good at that. They evolved over hundreds of millions of years to do that, to quickly and ceaselessly match sensed patterns to stored patterns. We recognize faces and music and seasons and we have little or no idea how to define them. We cannot explain how we recall a name or answer a question or have a new idea. We just do it. Our neural nets just do it. (Kosko 1993)*

Luchins (1942) conducted a series of experiments examining the effect of prior experience on problem solving. Luchins referred to this as the effect of *einstellung*. Luchins used the *water jar* problems where given three different sized jars the task was to arrive at a certain volume of water. For example; Jar A=21, Jar B=127, and Jar C=3, obtain 100 units of water. The result can be obtained by B-A-2C (127-21-3-3=100). The first five problems had jars of different sizes and different goals but could all be solved by this formula. The next two problems (six and seven) be solved in this way but could also be solved by a more direct route. For example, problem seven, A=23, B=49, C=3, obtain 20 units of water. The previous method works (B-A-2C=20), but the problem can be solved more simply by A-C=20. Luchins compared the way that subjects solved problems six and seven if they had previously completed the first five (experimental groups) with the way that subjects completed six and seven having done no prior problems (control groups). Subjects were 222 college students (aged 17-21), 913 adult high school students (aged 16-40), 1259 public school students (aged 9-14), 40 private school students (aged 8-12) and 275 university students (aged 19-52). About one third of the subjects were controls (no pre-conditioning) and the remainder experimental subjects. Luchins found that for all subjects virtually 100% of the control group subjects used the simple method. In stark contrast only around 25% of the pre-conditioned subjects chose the simple method, the remainder opting for the familiar but longer method.

Birch (1945), drawing on the work of Köhler, investigated the effect of previous experience on problem solving with chimpanzees. Six chimpanzees were given the use of a stick with which they could retrieve food from outside their cage. In 30 minutes only two of chimpanzees used the stick to retrieve the food; and one of these discovered the use of the stick by chance when bumping it and noticing the food moving. In contrast, all the chimpanzees solved the problem within 20 seconds, when the experiment was repeated following three days of being allowed to play with the sticks,. The results indicated that the chimpanzees were able to solve the problem by employing the knowledge gained through previous experience. However this experiment showed the *positive* value of previous experience rather than the potential negative effect.

Later, Birch and Rabinowitz (1951) showed the inhibiting effect of previous knowledge on problem solving. The task was to connect two strings hanging from the ceiling. The strings couldn't be grasped at the same time, however on the floor were two pieces of electrical equipment, a relay and an electric switch. Both items could be used as a weight to convert one string into a pendulum to complete the task. A control group of six electrical engineering students, familiar with the use of both objects, showed no bias toward either object; three using the relay and three using the switch. A further 19 college students who were not experienced with electrical equipment were divided into two groups. One group were trained to use the relay to solve an electrical circuit problem and the other group trained to use the switch to solve the same problem. The ten subjects who used the relay to solve the circuit problem all used the switch as the pendulum, whereas almost all (seven out of nine) of the subjects who used the switch to solve the circuit problem chose the relay as the pendulum. The pre-conditioning biased the later use of the objects. When asked for reasons, subjects tended to be defensive about their choice and its superiority over the alternative object. Both groups offered seemingly logical explanations; claiming their choice was easier to attach, more compact, heavier and so on.

Like Birch and Rabinowitz (1951), Schooler and Melcher (1995) demonstrated that previous experience can limit problem solving. Schooler and Melcher showed that poorly focussed photographs are more difficult to distinguish when subjects have previewed the same photograph even more poorly focussed (their methodology is not reported in detail).

Repetition, custom and habit have all been ways to express the same problem. Gardner (1982) said that the ability to copy and mimic are basic learning functions, however they can block the development of new ideas. Likewise, Osborn (1948) suggested that better recall abilities may even be a hindrance to creative thinking. It is recognised that the best abilities of the mind constitute something of a barrier to creative thinking. From this arises a need for mechanisms to aid the process of creativity; as Rickards said; '*...the need for lateral thinking arises because the mind does not record successive data in an objective way, but produces understanding through creating pattern.*' (Rickards 1988).

3.6 Uncreative Culture

Sometimes the cultural effects on creativity can be harsh. For example, despite being right, Copernicus became very unpopular by suggesting that the Sun was the centre of the solar system. The assumptions held by his detractors were learnt from their surroundings and experience. However, criticism, victimisation, short-sightedness, and ridicule, are not confined to uneducated times well past. Peters (1987) illustrated this with a number of more contemporary examples where creative ideas were subjected to harsh criticism that later proved to be very short-sighted.

‘*Who in the hell wants to hear actors talk?*’

Harry Warner, founder of Warner Bros. Studio, in 1927

‘*I think there’s a world market for about five computers.*’

Thomas J. Watson, Chairman of IBM, in 1943

‘*There is no reason for any individual to have a computer in their home.*’

Ken Olson, President of Digital Equipment, in 1977

Cultural rigidity and cultural barriers to creativity are not only features of the western world. ‘*The geniuses are kicked out*’! This was the comment of Tadatsugu Taniguchi, Molecular Biology Director at University of Osaka, about that way that the Japanese education system promotes evenness, overlooking individuals brilliant in special areas (in Bylinski & Moore 1987). Although a recognition exists of the industrial importance of innovation in Japan (Tatsuno 1990), their societal, cultural and education systems tend to obstruct creativity. These cultures equate seniority with wisdom, suppresses individuals in favour of groups, values improvement little-by-little rather than concept changes, and resists the conflict that often comes with creativity (Bylinski & Moore 1987).

It seems that like our brain, our way of living prefers order. Parnes (1971) said that ‘*In a society each individual must live in a box, hemmed in somewhat*’. A post to creativity discussion group captured elegantly the thinking limitations of a boxed-in lifestyle.

> *A few years ago I met some Indians from the Amazon rainforest visiting the US... I asked what they found interesting or surprising about the U.S. One of the things they offered was that they had always been confused by North American/European visitors to the rainforest because they all appeared to think and talk in boxes. After visiting NYC and other metro areas, they realized it was only natural. Everyone lived in small boxes, many of them stacked on top of each other. To them, this explained many of our conceptual limits (Baker 1995)*

In an attempt to compare cultures, Li and Shallcross (1992) investigated the difference between Asian and American students on the *nine dot* problem. Subjects were 80 Chinese and 80 American students split equally into four age groups (6-7; 10-11; 15-16; 17-18). Li and Shallcross measured several variables and found that the Chinese students;

- succeeded more often (43 compared with 17)
- went beyond the boundaries more often (55 compared with 38)
- took longer to break the boundary (32 minutes compared with 21 minutes)
- took longer to solve the problem (41 minutes compared with 26 minutes)
- took longer to give up (75 minutes compared with 30 minutes)
- took more trials to solve the problem (39 compared with 29)

The mean time that Chinese students took to solve the problem was 41 minutes. American students who did not solve the problem gave up after 30 minutes on average. Given that most of the Chinese success was beyond the 30 minute time, this seems to indicate that persistence is significant in the overall success of the Chinese compared to the Americans.

The lack of persistence is possibly linked to the issue of ego. Ego is a term intricately linked with social culture. In Freud's definition ego is social awareness and conscious. In social interaction the ego is a restriction to explorative thinking. For instance in the case of solving the nine-dots problem, if subjects fail to persist it may be because they don't wish to be involved in something at which they fear being incompetent. Once committed to a point of view, for instance that the task is impossible, there is not much incentive to continue. Social awareness (ego) leads people to be wary of looking foolish, being indecisive, changing their mind frequently or backing eventual losers. Like the response of the Editor of the Daily Express of London, when John Baird, inventor of television, wished to see him in 1925; '*For God's sake, go down to reception and get rid of a lunatic who's down there. He says he's got a machine for seeing by wireless! Watch him-he may have a razor on him*' (in Peters 1987).

Adams (1987) reasoned that fear to make a mistake, to fail or to take a risk are common emotional blockages to new ideas. Some authors cite the strong ancient Greek influence as the basis for this passion for rightness. *'Western science took a full two-thousand years to liberate itself from the hypnotic effect of Aristotle.'* (Koestler 1969, p. 176)

The belief in a concept of a fixed truth encourages a search for the truth and the ego creates a desire to be *seen* to know the truth. Many authors have commented that spontaneous judgement of *rightness* is an obstacle to creative thinking (Osborn 1948; Gerard 1952; Perkins, 1981; Adams 1986; Rickards 1988). Osborn (1948) said that judgement is a safe kind of thinking as it produces only a verdict rather than an idea. Gerard concurred and said that judgement often rejects new ideas.

> *For ideas, like mutations, are mostly bad by the criteria of judgement, and experience and expertness suppresses them - unless imaginings get out of hand and displace reality, as in the insanities. (Gerard 1952, p.227)*

In summary, the *box* that creative thought escapes from, is a box of assumptions, a box of perception based on past experience and learnt patterns. Originality is characterised by an altering of perception, a break from the boundary. There is not only the conservative nature of the mind to cope with but the conservative nature of social and cultural interaction. Rickards (1988) noted that *yes, but...* was the most likely retort to a new idea and that this expression represents the epitome of judgemental thinking. The message is that methods to provoke thinking out of dominant boundaries and ways to be sympathetic to seemingly illogical ideas are vital for a real change of paradigm. Gary Larson (1992) characterised the superficiality of many creative efforts when thinking becomes embedded in habit (Figure 3-6).

The writers for "Bewitched" sit down to their weekly brainstorming session.

Figure 3-6 A Cartoon Comment on Superficial Thinking Embedded in Habit (Larson 1992)

3.7 Intelligence

Early definitions of thinking were such that thinking was only subliminal movement of the vocal chords. Thinking was no more than talking to yourself. Words *were* thinking; and therefore good thinking *meant* good verbalising (Koestler 1969).

Language has subsequently dominated education and in the assessment of intelligence its role has always been central. The dominance of language skills, and mathematical skills, in the assessment of intelligence has been widely criticised on the basis that the tests attempt to determine a single value and are too narrow in their approach (for example; Gardner 1985; Guilford 1987; Sternberg & Lubart 1995). Gardner (1985) suggested that intelligence tests show past learning rather than future potential. They reveal little about a person's ability to re-organise information or solve a new problem. Gardner illustrated the problem by showing that some people who were excellent in some areas of thinking, were poor in others. For example, Leonardo da Vinci is upheld as being creative in many areas but was not particularly good at music. Thus, if IQ tests were based on musical intelligence, da Vinci would be classified as unintelligent. Similarly, Adams (1987) commented that tests based on good skills in mathematics and language (often the hallmarks of intelligence and school testing) lead to similarly poorly based claims that those who do well have high intelligence, and those who do poorly have low intelligence. These contemporary writers echoed the sentiments of Dewey's earlier writing.

> *The conviction that language is necessary to thinking (is even identical with it) is met by the contention that language perverts and conceals thought. Three typical views have been maintained regarding the relation of thought and language: first that they are identical; second, that words are the garb or clothing of thought, necessary not for thought but for conveying it; and third (the view we shall here maintain) that while language is not thought it is necessary for thinking as well as for its communication. (Dewey 1910, p. 170)*

Verbalising to memorise is a common way for western people to learn. Hebb (1949) described an experiment where subjects were asked to remember an image of 16 characters arranged in a four-by-four matrix. The image was typically recalled in the familiar, left to right, horizontal orientation, showing that that the stored image of the square was not remembered as a spatial image but memorised according to the normal reading culture.

While words are useful for reading, are they useful for thinking? Michael Faraday *saw* the stresses surrounding magnets and electric currents as curves in space. James Maxwell made mental images of problems, that is *symbols without words* and Francis Galton said '*I fail to arrive at the full conviction that a problem is fairly taken on me unless I have continued somehow to disembarrass it of words*' (in Gordon 1961). Einstein commented that words are useful for describing thinking but have little to do with the thinking itself.

> *The words or the language, as they are written or spoken, do not seem to play any role in the mechanism of thought. The physical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be voluntarily reproduced and combined. (Einstein 1952, p. 43)*

While words are certainly useful for analysis, description and communication they are not necessarily a part of the actual process of thinking (Einstein 1952). Yet formal thinking is dominated by verbal logic as the main form of thinking (Kornhaber & Gardner 1991). Relying only on analysis, description and logical explanation of the way the things are perceived to be is a major cause of irrationality and an obstacle to creative thinking (Adams 1989; de Bono 1992a). Many authors have suggested that Western education systems have a large responsibility for building barriers to creativity by promoting judgemental thinking (Osborn 1953; Torrance 1962; Rickards 1988).

While language has dominated the testing of intelligence, models of the functions of the mind have for a long time considered wider range of factors; the *five senses* perhaps constituted the simplest model of this type. Spearman (1930) vigorously questioned the validity of assumptions made about intelligence and intelligence testing. Spearman felt there was some commonality in intelligence, or a *general* intelligence, and yet was dissatisfied with the indiscriminate application of intelligence tests that measured one aspect and then transposed this to indicate overall intelligence. Recently Guilford (1987) commented that the attention given to language has been to the detriment of creativity.

> *It should be remembered that from the time of Binet to the present, the chief practical criterion used in validation of tests of intellect has been achievement in school. For children, this has meant largely achievement in reading and arithmetic. This fact has generally determined the nature of our intelligence tests. Operationally then, intelligence has been the ability (or complex of abilities) to master reading and arithmetic and similar subjects. These subjects are not conspicuously demanding of creative talent. (Guilford 1987, p. 36)*

In 1909, Binet (1975), who somewhat ironically was also one of the first involved in the development of intelligence tests for children, said that good teaching must activate a full range of senses. Some years later, Hebb (1949) found that patients with the entire right cortex removed could often still achieve excellent IQ scores. Hebb suggested that this showed that good *language skills* are commonly associated with high intelligence, while the skills more strongly associated with the right cortex are not measured. It seems commonplace for those with poor speech to be seen as having an impaired intelligence. For instance, it would be rare for someone lacking in musical ability to be labelled *retarded*, but labels like these are often unfortunately ascribed to those with poor speech. Torrance said that *'...it is safe to say that IQ represents a gross oversimplification of human giftedness'* (Torrance 1992, p. 10), while Dewey (1910) earlier commented that signs are necessary for thinking, but *words are not the only kind of sign*.

> *...language includes much more than oral and written speech. Gestures, pictures, monuments, visual images, finger movements - anything consciously employed as a sign is, logically, language. (Dewey 1910, pp. 170-171)*

While the actual testing of intelligence concentrated on abilities in the verbal and mathematical area, it has been well recognised that there are clearly a range of other ways that intelligence can be expressed.

The brain cortex is usually described in terms of a left and right hemisphere and so there has been much interest in determining which types of intelligences relate to which hemisphere. The division of the brain into two parts has been known for several hundred years (Blakemore 1990). Thomas Willis in 1661 began dissecting brains and came to the conclusion that perception, memory, voluntary activities and so on, occur in the cerebral hemispheres. Mainly during the last century there has been a mapping of functions to certain areas of the brain. In the 1960's, Sperry, Gazzaniga and Bogen (1969) conducted experiments with patients whose brain hemispheres had been disconnected. They observed that each of the separated hemispheres had its own visual sensations and memory, however the left hemisphere was dominant in verbal and mathematical tasks. Their testing equipment involved a patient looking at a screen, on the back of which could be projected silhouette images. The patients could reach under the screen to manipulate objects, but could not see past the screen. In one experiment the patient was asked to fix vision on the centre of the screen. Two images were projected for 1/10 second; one on the left field and one on the right. If asked to select the object they saw, by feeling with the left hand, the patient selected the object matching the left-field image. When asked to *name* the *same* object the patient responded with the name of the object in the right-field. Objects seen in the left-field, or manipulated with the left-hand, could not be verbalised, whereas those on the right-side could be verbalised. Similar effects were shown for mathematical tasks. Under normal conditions, where the eyes scan all around, these results were not found and speech and mathematical ability appear normal. From these studies and others, the functions dominated by each hemisphere are usually described as follows.

Left Hemisphere	***Right Hemisphere***
Words	*Spatial*
Logic	*Perception*
Numbers	*Imagination*
Sequence	*Rhythm*
Symbols	*Colour*
	Wholeness
	Dimension

Table 3-3 Typically Cited Dominant Functions of the Left and Right Hemispheres

Sperry (1983) later suggested that most education focuses on the development of the left hemisphere. This has perhaps been to the detriment of creative thinking, that is thought to importantly involve reorganisation, imagination and so on. As a result methods that are supposed to promote thinking using the right-hemisphere have made their way into many texts on creative thinking. For instance, the spatial technique of taking notes, known as mind-mapping, mainly promoted by Buzan (Buzan 1974; Buzan & Buzan 1993), is based on tapping a non-linear type of thinking (Figure 3-7).

Mind Maps

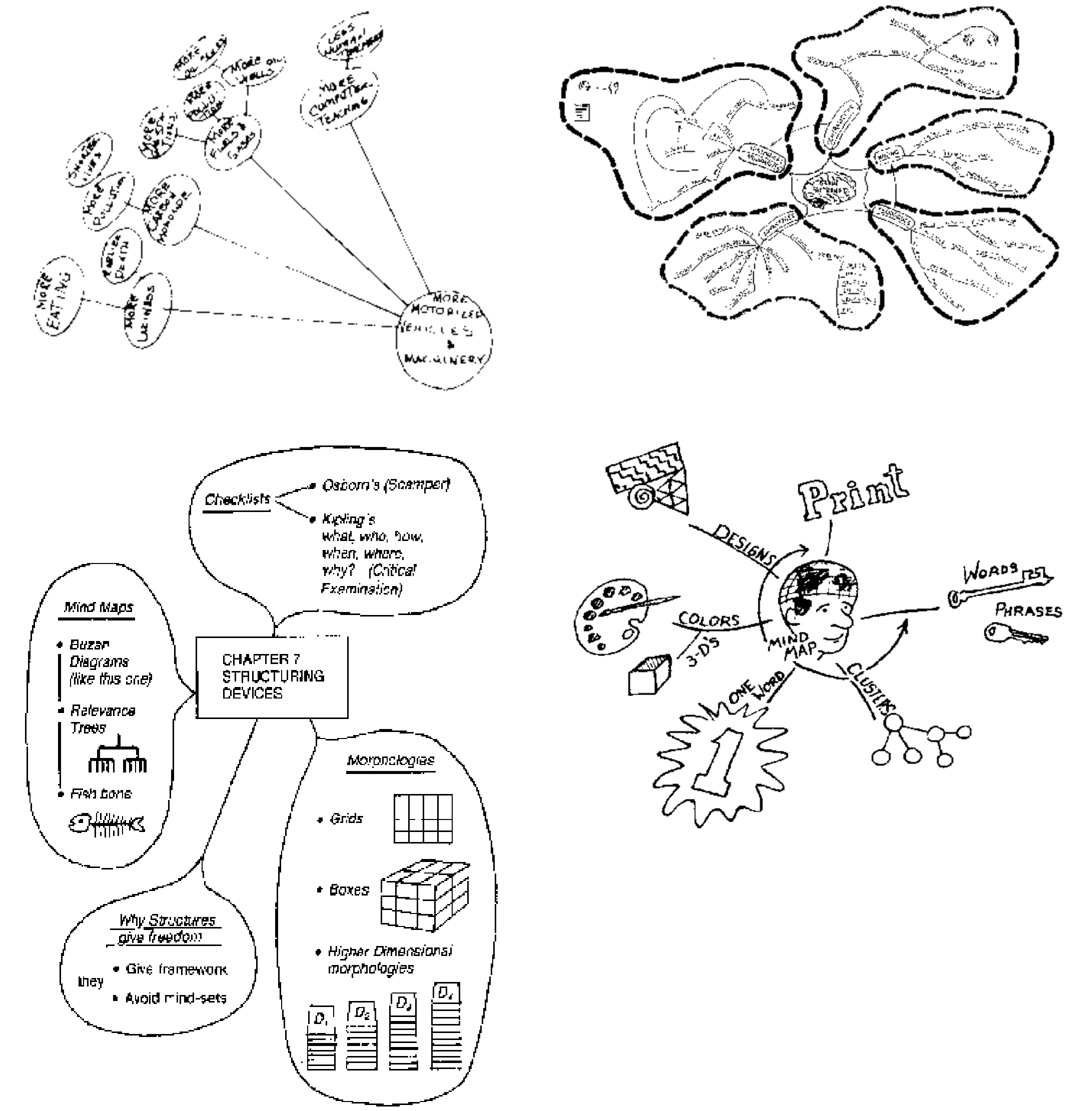


Figure 3-7 Examples of the Structure and Layout of 'Mind Maps'
Clockwise from Top Left: Glenn 1973; Buzan 1974; Lazear 1990; Rickards 1988

The left/right brain model has appeared in many texts and research studies of creative thinking. For instance, Williams, Stockmyer and Williams (1984) compared brainstorming with a program designed to activate both sides of the brain. Subjects were 62 undergraduate students in two equal-size groups who were required to think of similarities between an island and a school. They found a similarity in the number of ideas, but the techniques to stimulate both sides of the brain lead to more creative ideas.

However some authors have suggested that the distinctions are over-played and are not nearly as clear as the typical lists indicate (for example; Sperry 1983; Dobbs 1989). Gardner (1982; 1985) claimed that no function resides wholly in any one area of the brain; some areas simply are *relatively* more important for certain functions. Correspondingly, Perkins (1981) said that drawing conclusions like intuition and rationality lie in the right and left brain respectively involves definitions far too loose to be of practical use. Sperry, awarded a Nobel Prize for work in this area, summed up the difficulties of the typical classifications with the following comment.

> *One must caution in this connection that the experimentally observed polarity in right-left cognitive style is an idea in general with which it is very easy to run wild. You can read today that things such as intuition, the seat of the subconscious, creativity, parapsychic sensitivity, the mind of the Orient, ethnocultural disposition, hypnotic susceptibility, the roots of the counterculture, altered states of consciousness, and what not, all reside predominantly in the right hemisphere. The extent to which extrapolations of this kind may eventually prove to be more fact or fancy will require many years to determine. Meanwhile it is important to remember that the two hemispheres in the normal intact brain tend regularly to function closely together as a unit, and that different states of mind are apt to involve different hierarchical and organizational levels, or front-back and other differentiations in laterality. (Sperry 1985, p. 19)*

While the left and right model of the brain is probably the most pervasive, there have been other ways to split up the functions of thinking. Guilford introduced the widely accepted structure-of-intellect (SOI) model, a cubic morphological model of intellect (Guilford 1967; Figure 3-8).

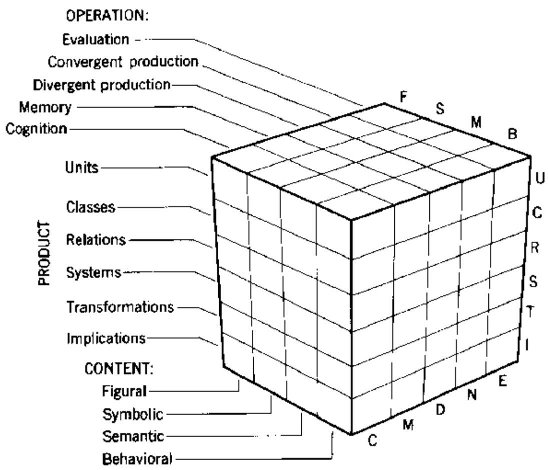


Figure 3-8 Structure of Intellect (SOI) Model (Guilford 1967)

The SOI model consisted of a cube; each dimension representing a series of related intellect factors. Guilford (1988) later extended the model to include a greater number of factors; dividing memory into memory retention and memory recording, and dividing figural content into visual and auditory content. The factors then consisted of the following.

1. Content
Visual (visual-figural)
Auditory (auditory-figural)
Symbolic (signs, symbols, words)
Semantic (thoughts, without visual or auditory images)
Behavioural (behaviour cues such as body language)

2. Products
Units (any bit of information)
Classes (grouping due to similarity)
Relations (one thing directly related to another)
Systems (organised units)
Transformations (the change of something into another)
Implications (one thing associated with another)

3. Operations
Cognition (knowing)
Memory Recording (holding on to the knowing long-term)
Memory Retention (holding on to the knowing short-term)
Divergent Production (generation of alternatives)
Convergent Production (looking for one answer)
Evaluation (judgement)

Guilford (1988) wrote that experiments employing the technique of factor analysis have shown that over 100 of the 180 potential abilities have been individually demonstrated. The model provides a mechanism for understanding intelligence and creative abilities in a broad sense. Recently there's been growing educational interest in a similar, but simpler, model proposed by Gardner (1985).

Gardner suggested that intelligence could be usefully divided into seven intelligences; linguistic, mathematical, musical, body kinaesthetic, spatial, interpersonal, and intrapersonal intelligence. Hatch and Gardner (1990) undertook a project with a small sample of preschool children with a series of intelligence evaluation tools that were designed to reflect a broad range of intelligences, loosely related to Gardner's multiple intelligence model. They found that the children's strengths in various areas were unrelated to strengths in other areas and that standard Stanford-Binet (IQ) scores only correlated well with mathematical functions. The multiple intelligence model would seem to share a similarity with the *content* factors in Guilford's model, with a few modifications and additions. While Gardner's model has not received the research interest of Guilford's, it seems to be having a growing influence in the educational field. The model provides a simpler approach than Guilford's and while the terms may not be validated in a scientific sense they provide a model for widening the scope of activity that might be designed in to class activities and tests. Much like the split of functions into the hemispheres encouraged development of tools like mind mapping, Gardner's model may at least serve to highlight a range of thinking skills; a worthwhile outcome for the enhancement of creative thinking. As evidence of the validity of such an approach, studies have shown that physical exercise (Gondola 1986; Curnow & Turner 1992), and especially aerobic exercise (Hinkle, Tuckman & Sampson 1993) can improve creativity. Others have shown that programs involving music (Curnow & Turner 1992), dance (Flaherty 1992), creative arts combining physical expression such as dance and visual art (Gruber, McNinch & Cone 1991; Goff 1992), and programs designed to enhance self-control of thinking (Berretta & Privette 1990) can be worthwhile in enhancing creativity.

If the studies of intelligence have aided the study of creativity it is by showing the importance of encouraging broad application of thinking abilities. Various models that expand the notion of thinking, such as the simples *senses model,* the *hemispheres model,* Guilford's *structure-of-intellect model,* or Gardner's *multiple intelligence model* all serve to encourage thinking to be considered in wider terms than language and logic.

3.8 Active Divergent Thinking (ADT)

Einstein suggested that the process of productive thought involved the manipulation or combination of abstract ideas.

> *...from a psychological viewpoint, this combinatory play seems to be the essential feature in productive thought-before there is any connection with logical construction in words or other kinds of signs which can be communicated to others (Einstein 1952, p. 43)*

Thus according to Einstein, productive thought was not logical, but abstract. Logical descriptions or explanations came *after* this abstract thinking. Psychologist, Abraham Maslow (1965) agreed and said that making connections and reforming ideas in a new way will require patience or perhaps an acceptance of uncertainty, wrongness and ambiguity.

It was noted above that often a fortuitous event provided the inspiration of divergence from the established train of thought. Guilford referred to this kind of thinking as divergent thinking. The techniques that aim to increase the likelihood of the movement of thinking outside dominant paradigms I've labelled *active divergent thinking*. The term, *active,* meaning that the thinker takes deliberate steps to encourage divergent thinking. A summary of the main techniques or features of active divergent thinking follow.

3.8.1 Chance

The classic tales of creative success often involve a seemingly fortuitous combination of the problem at hand with a useful by-chance event that jogged the thinking into a new mode. Mednick (1962) used the term *serendipity* to describe the by-chance association that is a typical part of famous incidents of creative inspiration. Mednick (1962) suggested that the central element of creativity is the association of previously unassociated elements. Waiting for these events is unreliable and so the active use of chance has been suggested as a way to bring more certainty to the process. For instance, introducing a random word or random object has been suggested as a simple way to stimulate new perception of a problem (Mednick 1962; de Bono 1971).

> *A useful technique that sometimes helps towards the formation of new ideas or new ways of looking at things is to pick an object out of the environment and then try to see how it could be relevant to the matter under consideration. The supposition is that if both the objects and the problem are simultaneously held in consciousness, some sort of context will gradually develop to embrace them both. (de Bono 1971, p. 104)*

3.8.2 Analogy

Ribot (1906) considered that analogic comparisons to be the centre of creative thought. Many writers since have promoted its use as a creative thinking technique (Gibson & Phillips 1958; Gordon 1961; Koestler 1969; de Bono 1971; Bransford & Stein 1984).

> *A further technique for breaking down the rigidity of a particular way of looking at things is to transfer the relationships of the situation to another more easily handled situation. (de Bono 1971, p. 80)*

The *synectics* model (Gordon 1961) is probably the most well-known for using analogy as a method for active divergent thinking. In 1944 Gordon and others instigated the *Synectics* program at Cambridge University. Synectics, a Greek word, means joining together different or apparently irrelevant elements and reflected the diversity of the group membership. However, synectics later related to the creative processes of analogy that the program emphasised. The method is now commonly mentioned, sometimes as *synectics*, or sometimes just as analogy. Barry and Rudinow (1990) suggested using analogies to relate difficult problems to simple problems. They used the example of a ping pong tournament with 208 competitors. The tournament is a knock-out and the problem is to work out how many matches are needed to arrive at the winner. Often people approach the problem using a tree diagram or a mathematical technique. An alternative is to draw an analogy between the 208 entrant tournament and a tournament with two entrants. Clearly only one match would be needed. With three entrants, two would be needed. It is then apparent that 207 matches will be needed for the 208 entrant tournament.

Analogy between the moving parts in an ear and an idea for a telephone is supposed to have helped Alexander Graham Bell to invent the telephone. Gutenberg is thought to have invented the printing press by drawing an analogy between a wine press and a coin stamping machine. Analogies make new things familiar by comparison to already understood ideas. Halpern (1989) said that analogies used in this way make understanding new or complex things less difficult. In the examples of inventions cited earlier, analogy was often part of the development of a new idea.

Bouchard (1972) compared brainstorming with and without the technique of *personal analogy* as described by Gordon (1961). Subjects were 44 undergraduate students arranged into three groups of four who brainstormed using the analogy method and eight control groups of four who brainstormed in the usual way. Each group worked on nine *alternative uses* problems in three sessions. The subjects in the groups using personal analogy were instructed to take turns at acting like the object in question (for example they had to pretend to be a cigar when this was the object). The results showed that for the first session (three problems) the personal analogy groups generated significantly more ideas (100%) than the control groups. However in the subsequent two sessions (six problems) the analogy groups were not significantly better. There were indications of success, however Bouchard did not conclude with certainty that the personal analogy technique improved idea generation.

In addition to sometimes being known under the synectics banner, *bisociation* has been used to describe analogic thinking (Koestler 1969). Bisociation meant the linking of concepts, or in Koestler's terminology, *thinking on two planes rather than one*. The technique of bisociation was to amalgamate two normally unconnected ideas which is another way of expressing the idea of analogy. The purpose of analogy as an active divergent thinking technique is to establish *links* by association. Often this association shifts perception showing the situation in a new light.

3.8.3 Forcing Relationships: Morphology

Forcing ideas together can be an effective method to generate new ideas (Parnes 1967). Putting this into practice can be achieved via the technique of morphology as described by Allen (1962) and Zwicky (1969). Morphology is the practice of idea combinations usually using a matrix. Morphology has since been widely discussed in texts on creative thinking (for example; Koberg 1981; Adams 1986; Rickards 1988). Sometimes the method is called attribute analysis, especially when related to product design (Parnes 1976; Adams 1986). As an example of product design, Table 3-4 shows Allen's matrix for the design of a kettle.

Container Construction	***Metal Used***	***Type of Bottom***	***Automatic Heating Controls***	***Capacity (Quarts)***	***Power Rating (Watts)***
Pressed	*Aluminium*	*Single Metal*	*Underneath Kettle*	*2*	*500*
Case	*Stainless Steel*	*Double Metal*	*On Kettle*	*3*	*850*
Single Wall	*Copper*	*Solid*	*On Handle*	*5*	*1350*
Double Wall		*Double Bottom*	*On Cord*	*8*	*2000*
With Air Space		*With Air Space*			

Table 3-4 Morphological Matrix (*Morphologizer*) to Design a New Kettle (Allen 1962)

By thinking of the relevant parameters, and then developing a few options for each parameter, the resultant combinations soon amount to a large set of options. The kettle matrix has six parameters with only three or four options for each parameter, and yet this yields 3000 different kettles. Listing the 3000 options would be monotonous and many options would seem not too different from many others, however the power of the technique comes by way of forcing relationships that would ordinarily be not considered, and by opening an appreciation of the many variations that are possible.

As a further example, Niemark (1987) reproduced the following phrase generator (Table 3-5). Choosing a random number such as 241 or 735 yields impressive phrases like *diverse harmonious awareness* or *realistic dialectical response*. The method force fits words together and provides a fast way to generate a phrase. Although a little facetious, this example shows random combinations to be a powerful method of idea generation.

	Column A	***Column B***	***Column C***
1	*Profound*	*Interpersonal*	*Awareness*
2	*Diverse*	*Emotional*	*Oneness*
3	*Genuine*	*Dialectical*	*Relationship*
4	*Subjective*	*Harmonious*	*Network*
5	*Complex*	*Communal*	*Response*
6	*Sophisticated*	*Open*	*Linkage*
7	*Realistic*	*Humane*	*Consensus*
8	*Meaningful*	*Interactive*	*Context*
9	*Mutual*	*Collective*	*Dialogue*
0	*Objective*	*Societal*	*Forum*

Table 3-5 Phrase Generator (Niemark 1987)

The element of active divergent thinking in morphology is to employ the matrix to *force* a *link* between ideas that are not normally linked. The technique thus employs the principle of combinations as a thinking diversion.

3.8.4 Brainstorming

> *Brainstorming: a technique in which a group meets in order to stimulate creative thinking, new ideas, etc (The Macquarie Dictionary 1985)*

Brainstorming is probably the most well-known term in creative thinking. Alex Osborn (1948) first used brainstorming at his own company in 1939 and it has since become a popular method for creativity. For instance, Fernald and Nickolenko (1993) recently surveyed 1000 businesses in Orlando about creative methods. One hundred responded and the results showed that brainstorming was the most frequently mentioned technique. According to Osborn, the name brainstorm meant to use the *brain* to *storm* a problem. Osborn said that at least four hundred years ago, Hindu Indians practiced a group creative process called *Prai-Barshana*. *Prai* meaning *outside yourself*. *Barshana* meaning *question*. The process of prai-barshana thus meant to question outside yourself; to air the thinking in a group. Osborn's brainstorming rules were;

> *1. Judicial judgement is ruled out. Criticism of ideas will be withheld until the next day.*
> *2. "Wildness" is welcomed. The crazier the idea, the better; it's easier to tone down than think up.*
> *3. Quantity is wanted. The more ideas we pile up, the more likelihood of winners.*
> *4. Combination and improvement are sought. In addition to contributing ideas of our own, let's suggest how another's idea can be turned into a better idea; or how two or more ideas can be joined into still another idea. (Osborn 1948, p. 269)*

These rules were intended to create a setting for the generation of ideas. Osborn suggested that the first rule was most vital as attempting to combine idea creation and criticism is like getting hot and cold water out of a tap at the same time (Osborn 1948). The theory was that deferring judgement overcame education and experience that encouraged judgment and criticism. Ideas are much like seedlings in that they are easily trampled when they first appear and require a little nurturing before they are judged critically. Osborn suggested that judgement must be deferred for two main reasons.

1. Sometimes the suggestions may change the *parameters* of the problem.
2. Ideas of little value may be modified or lead to worthwhile ideas.

Following experience with brainstorming, Osborn (1979) claimed that the more ideas that are produced the higher the quality becomes. That is, the best ideas tend to be developed near the end of the session. The message therefore was to create an abundance of ideas and then choose the best. However Adams (1987) said that the natural tendency is to choose the first one that comes to mind. Osborn stressed the importance of multiple options for two reasons. Firstly, more options increases the probability of a worthwhile idea, and secondly many ideas encourages associations; a chain reaction. However getting started can be difficult. Blank paper is threatening and anything put on it will stand out. If judgement is deferred then starting should be easier. This has a snowball effect as once there are a few ideas it seems less threatening to add one or two that even seem a bit silly. Connections and modifications are easier to make once the list grows. The principle of the generation of alternatives as a key feature of problem solving seems universal among creativity literature (for example; Guilford 1950; Kogan & Bagnall 1981; Adams 1987; Sventesson 1990).

While Osborn is best known for promoting brainstorming in groups, he made observations that group idea generation was not always the most efficient.

> *For one thing, during certain periods in a creative quest, each member of a team should go off by himself and do some brainstorming on his own. When the partners come together after such solo thinking, they will find that they have piled up more worthwhile alternatives than if they had kept on working as one all the time. (Osborn 1948, p. 264)*

Group work has a strong connection to creativity. The techniques of brainstorming are applicable to individual work, however the group setting of brainstorming has been strongly associated with the method. This is in part due to considering creativity as a trait of people. If some people are creative and some are not, and it's difficult to tell the difference between them, then the best way to ensure a creative result is to mix a few people together. Hopefully one of them is creative and will spur the others forward.

Gordon (1961) wrote that the common approach to creativity is as follows; '*I will select creative people, but since creativity is so mysterious and unpredictable, I may have missed on some, so I will put several together and hope for the best*'. Gordon (1961) said that the team using an undisciplined approach degenerates toward the safest, most obvious and most superficial solution available; far from the cooperative ideal of group creativity.

Brainstorming provided a setting for idea generation. As noted already the central element to creativity is a change in perception, a move outside the square. Osborn's (1948) model included techniques for active divergent thinking, but in many ways they have been overshadowed by the brainstorming model. The techniques Osborn (1948) suggested for promoting divergent thinking was the following list of *focussing verbs*.

1. *Seek alternatives*
2. *Find other uses*
3. *Find similar ideas and copy*
4. *Modify*
5. *Magnify*
6. *Exaggerate*
7. *Minify*
8. *Substitute*
9. *Re-arrange*
10. *Reverse*
11. *Combine*

(Focussing Verbs; Osborn 1948)

The checklist provided ways to jog thinking from dominant paradigms. The method requires discipline and focussed effort to explore the resulting possibilities. For instance, a suggestion like *magnify* may initially lead to no ideas, but some effort must be made to follow this train of thought, otherwise perceptions remain unchanged. The purpose of focussing verbs is to actively divert the mind in a direction that might not occur if old habits are allowed to dictate.

Osborn's personal experience of brainstorming was in the advertising industry. De Bono (1992a) has been critical of brainstorming and suggested that the advertising industry relies on novelty and that this approach is not always appropriate where ideas must have greater serious application. Likewise, Osborn intended brainstorming to be purposeful.

> *But in almost every other field a scatter-gun approach to creativity makes no more sense than having a thousand monkeys banging away on typewriters in the hope that one of them might produce a Shakespeare play. (de Bono 1992a, p. 39)*

> *The first rule is that the problem should be specific rather than general-it should be narrowed down so that the brainstormers can shoot their ideas at a single target. (Osborn 1948, p. 268)*

It may be that Osborn's intention of a specific purpose for brainstorming session has been poorly adopted. Perhaps the generation of wild ideas has become the main thrust of many brainstorming efforts? The scattergun approach clearly would be a normal and necessary feature of the free-association of brainstorming, but hopefully this approach would be taken within the confines of a certain domain. Alternatively the employment of focussing verbs as tools of active divergence do not necessarily involve free association; the new ideas may arise not from enthusiastic association but through forced divergent thinking.

In terms of the success of the brainstorming model, Osborn cited examples from many organisations and people that attested to its value. These examples appeared to be an indication of the usefulness of the process and its continued popularity has lead the term brainstorming to be synonymous with creative thinking. Further to this there have been many studies that examined the effect of brainstorming (discussed later). In some studies the method was described as the Osborn-Parnes method and as such this deserves a brief explanation. The term Osborn-Parnes refers to the process Parnes (1967) developed based on the brainstorming model. The Osborn-Parnes model consisted of the steps outlined below. The model was a problem-solving framework around the *brainstorming* core.

1. *Understanding problems, problems as opportunities*
2. *Defining the problem, what is the real problem, Asking 'Why?'*
3. *Deferring judgement (brainstorming model) and challenging habits*
4. *Forming associations*
5. *Evaluating ideas*
6. *Putting ideas into action*
7. *Finding; facts, problems, ideas, solutions and acceptance*
8. *Observation and perception*
9. *Applying the total process to practice problems*
10. *Using checklists for idea finding (Osborn's tools)*
11. *Making unusual ideas useful*
12. *Applying total process to own problems with direction*
13. *Forcing relationships, morphology and matrix*
14. *Applying total process to own problems, self-directed*
15. *Making snap decisions*
16. *Summary*

(Osborn-Parnes Problem Solving Method; Parnes (1967))

In summary, Osborn recognised many of the typical blockages to creative thought and sought to overcome these with a set of simple rules for group meetings that would facilitate free expression, combination of ideas and exploration of seemingly weak possibilities. These rules also applied to individual thinking although were often applied in a group setting. Furthermore Osborn recognised that creative thinking could be enhanced by techniques that provided a way to actively divert thinking from its well-worn pathways. This part of the model has been overshadowed by the brainstorming rules for group efforts.

3.8.5 Lateral Thinking

> *Lateral thinking: a way of thinking which seeks the solution to a problem by making associations with apparently unrelated areas, rather than pursuing one logical train of thought (The Macquarie Dictionary 1985)*

Lateral thinking characterises *thinking outside the boundary*. In many ways its usage as a term for creative thinking is convenient being not associated with artistic endeavour. In connection with creative thinking, the use of the term *lateral thinking* arises from the work of de Bono (1971) who defined main features of lateral thinking as follows.

> 1. *Recognition of dominant polarizing ideas.*
> 2. *The search for different ways of looking at things.*
> 3. *A relaxation of the rigid control of vertical thinking.*
> 4. *The use of chance.*
>
> *(de Bono 1971, p. 68)*

De Bono characterised lateral thinking with the diagram below (Figure 3-9) showing that lateral thinking is a jump from the obvious. While the side path looked small, once the jump is made the pathway appears as wide as the original path. Like Koestler (1969), de Bono (1992a) described lateral thinking as a way of thinking that we normally associate with humour. A punch-line delivers an alternative way of seeing the situation described in the main body of a joke. Similarly, lateral thinking describes a way of thinking that diverts off the main path to potentially show another way of looking at a problem.

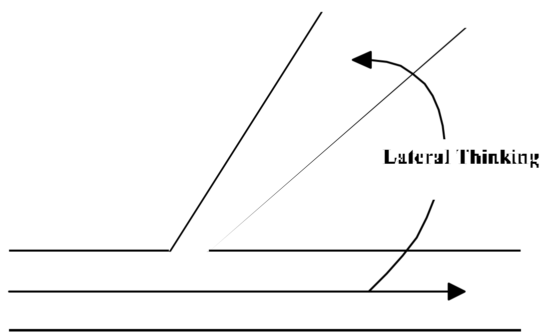


Figure 3-9 Lateral Thinking (de Bono 1992a)

The model employs the classic, *outside the square* model of creative thinking, but moving outside the dominant ways of thinking requires some stimulation. Escaping from the well-worn path can be firstly achieved by recognising the dominance of the path. Creating the new idea can be achieved by a deliberate examination of current assumptions and making a challenge to these assumptions. De Bono (1971) called this *recognition of dominant polarizing ideas*. Once assumptions are recognised they can be challenged by first simply attempting to find another way to view the situation. More directly though, the assumed boundaries can be challenged directly by employing processes such as Osborn's (1948) *focussing verbs* as prompts. Alternatively the problem domain might be shifted by the introduction of a random word, or perhaps by analogy to another situation, or maybe by deliberately reversing an assumed relationship.

> *Another useful technique is to turn upside down deliberately by consciously reversing some relationship. Instead of looking at the walls of a house as support for the roof, the walls may be considered as suspended from the roof. (de Bono 1971, p. 79)*

As noted so far restructuring of ideas in a new way is pivotal to creativity. Often this can be facilitated by forcing thinking outside current patterns. The divergent thinking techniques to achieve this shift often result in unreal or illogical concepts. As noted earlier, Einstein observed that many of his constructing thoughts involved illogical ideas. To facilitate the consideration of possibilities brought about via divergent thinking, de Bono (1969) introduced the word *PO*.

> *The whole purpose of PO is to provide a temporary escape from the discrete and ordered stability of language which reflects the fixed patterns of a self-organizing memory-system. (de Bono 1969, p. 287)*

Sometimes it is necessary to consider an idea that is an impossibility to subsequently arrive at a new, possible, idea (Rickards, 1988). PO can act as a signal that an idea is intended to be provocative, intended to be a stepping stone, rather than a firm, fixed idea. PO is simply a word to facilitate the processes important in creative thinking.

Lateral thinking then is in some ways synonymous for divergent thinking. The techniques associated with the term involve the recognition and challenging of dominant ways of thinking and the injection of stimulation to encourage *thinking outside the square*.

3.8.6 Six Thinking Hats

The tendency in our culture toward critical thinking and judgement is recognised as a major obstacle to creative thinking. As such Osborn's model of brainstorming in groups placed great importance on the elimination of criticism. Similarly, de Bono's (1985) six thinking hats tool can separate phases of thinking into bite size pieces thus offering the opportunity to be focussed on creative thought at one time and the judgement of ideas at another time. The six hats represented six modes of thinking (Table 3-6).

Metaphor	**Focus of Thinking**
Green Hat	Creativity, alternatives, possibilities
Yellow Hat	Benefits, values, opportunities
Black Hat	Caution, risks, judgement
Blue Hat	Control, managing the thinking
Red Hat	Emotion, feelings, intuition
White Hat	Information, facts, data

Table 3-6 Six Thinking Hats (de Bono 1985)

Obviously these words described the kind of thinking that all people do sometimes. Thus rather than anything new in the way of content, the six hats represented a way to structure thinking. The method aimed at providing a better way to organise thinking to achieve greater thinking breadth. One of the main reasons for this was to overcome a common tendency for criticism and judgement to dominate our thinking. Clearly judgemental thinking is important however it is well recognised that overused it is a hindrance to idea production. The six hats method provides a model for focussing on one kind of thinking at a time, such as creative thinking. The model provides a way to signal that other types of thinking will be used at an appropriate time. In some ways the blue hat is the key to the system. The blue hat is the control hat; the *thinking about thinking* hat, planning when creative thinking is appropriate and when other types of thinking are appropriate.

The six hats method was intended to create a model of *parallel thinking* as against adversarial thinking. Parallel thinking meaning the situation where groups of people think in the same mode at the same time. Thus all the yellow hat thinking is done at the same time, all the black hat thinking at the same time, and so on.

The method promotes involvement. In de Bono's words it '*separates ego from performance*'. Often it seems that we are discouraged from thinking about both sides of an argument because we find ourselves committed intellectually to one side. Backing winners in a social sense, involves making early judgements and seeing them though whereas the six hats system encourages all people to put forward ideas on both sides. Everyone is able to contribute to the exploration without denting ego's as they are just *playing the game*.

The metaphor of *thinking hats* is a convenient way to signal various thinking modes for a number of reasons. Hats have been traditionally associated with thinking, for example; *put on your thinking cap*. The six hats represent roles which is in accordance with the traditional association of hats and roles. For instance police officers, chefs, baseballers, surf-lifesavers, are all easily identified by their hats. Hats are also physically near to the mind, and are also physically easy to swap around. Koestler (1969) used the symbol of the thinking cap to describe the switch of thinking necessary to recombine old data in a new way. He said that the most difficult form of thinking is the art of handling the same bundle of data as before but relating them in a different way; and this *virtually means putting on a different kind of thinking-cap for the moment* (Koestler 1969, p. 235).

Koestler highlighted that the thinking cap can be on for a *moment*; a switch of thinking for a set amount of time. This facilitates the key value of the six hats method which is to provide a focus on creative thinking at the exclusion of other kinds of thinking.

3.8.7 Illustration of the Process of Active Divergent Thinking

To illustrate the processes of active divergent thinking, consider the following examples.

3.8.7.1 Example One: The Monk and Mountain Trail

> *One morning exactly at sunrise, a Buddhist monk began to climb a tall mountain. The narrow path, no more than a foot or two wide, spiralled around the mountain to a glittering temple at the summit.*
>
> *The monk ascended the path at varying rates of speed, stopping many times along the way to rest and to eat the dried fruit he carried with him. He reached the temple shortly before sunset. After several days of fasting and meditation he began his journey back along the same path, starting at sunrise and again walking at variable speeds with many pauses along the way. His average speed descending was, of course, greater than his average climbing speed.*
>
> *Prove that there is a spot along the path that the monk will occupy on both trips at precisely the same time of day. (Koestler 1969, p. 183-184)*

Logical reasoning seems to indicate that it would be very unlikely for the monk to be in any one place at the same time on both days. Koestler cited an example of how a person with no scientific background solved the problem by visualising the monk travelling up and then superimposed the monk also travelling down. It was then clear that the monks must meet. Travelling up and down simultaneously is impossible and yet thinking about the problem this way lead to the solution. Logic can easily get in the way of a logical solution. An active injection of an illogical visual image lead to a logical solution.

3.8.7.2 Example Two: The Gardener and the Olive Trees

> *You're a gardener. Your employer asks you to plant four olive trees so that each one is exactly the same distance from each of the others. How would you arrange the trees?*
> *(Barry & Rudinow 1989, p. 376)*

Arrangements in a square or in a line didn't work. Three trees in a triangle worked but wherever the other one goes it is closer to some than others. To solve the problem I challenged what I was assuming about the problem. Trees are normally outside; as a challenge to this I considered the idea that the trees be indoors. This lead me to the possibility of having some of the trees on a different story of the house. The solution then seemed to be to have three trees on one level in a triangle and the other tree upstairs at the centre of the triangle. Given appropriate proportions the problem would be solved. Outside the house trees could be planted in a pyramid by using a small hill or depression. This solution is obvious and logical; but that doesn't mean that I found the solution by logic. Indeed putting the fruit trees inside had nothing to do with logic at all. As in the previous example, actively injecting an illogical challenge lead to a logical solution.

3.8.7.3 Example Three: Active Divergent Thinking and Safe Design

To illustrate the process of creative thinking in safe design, consider a piece of equipment found in many homes. Some time ago the ABC in Australia screened a program about the safety of exercise cycles. The main focus of the television program was the problem of children becoming caught in the moving parts. They investigated a number of exercise cycles and showed how the guarding of the wheel, chain, sprocket and so on, was often inadequate. The program was critical of the poor guarding on many bicycles. *Australian Standard 4092—1993, Exercise Cycles - Safety Requirements*, noted that there has been injuries to the fingers and hands of young children mainly involving the chains, sprockets, flywheel spokes and flywheel loading mechanisms. To solve the problem, the most obvious route would be to follow the advice of the Standard.

> *Guards shall be provided to protect dangerous parts at all locations which constitute shear, crushing, or drawing-in hazards, giving particular attention to the following:*
> *(a) The flywheel*
> *(b) The drive train*
> *(c) The flywheel loading mechanism. (SAA AS 4092-1993, p. 6)*

Exercise cycles in the stores now would seem to be guarded according to the standard, but are more expensive. Maybe safety comes with a price tag? In safety, the hierarchy of control model gives priority to elimination of the hazard. Therefore consider the following.

1. Hazard (*potential to cause injury*): Moving Parts
2. First Priority: Eliminate Moving Parts
3. Risk Control: Redesign the exercise cycle eliminating the wheel, chain and sprockets.
4. Outcome: Simpler, lighter, cheaper and inherently safer exercise machine.

In hindsight this is completely logical (Figure 3-10). The wheel serves no purpose. The necessary resistance could be built into the pedal crankshaft. This machine would seem to have potential to be cheaper and inherently safer, due to the absence of many of the hazardous parts. This example shows the value of adopting the hierarchy of control model. The focus on high-order *elimination* control lead to improved safety along with simultaneous benefits such as cost savings, and a lighter cycle with lower maintenance needs. This contrasts with the guarding options that involved increased costs and offered no side benefits. The hierarchy of control thus served as a means of actively diverting the thinking from the dominant paradigms.

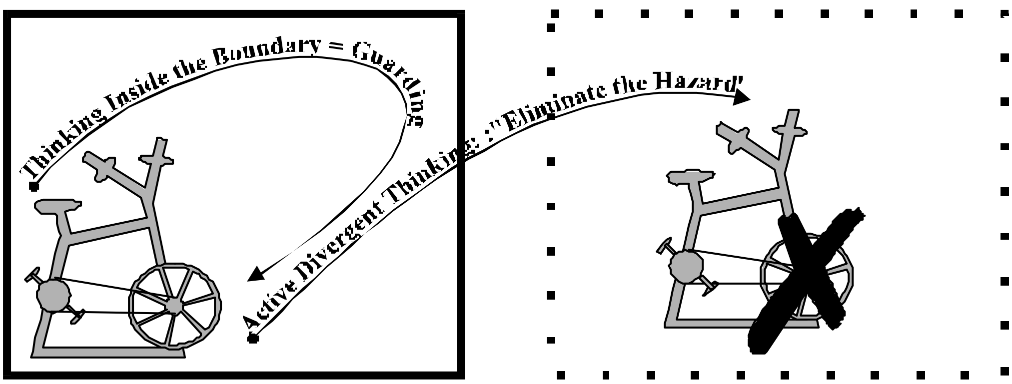


Figure 3-10 Active Divergent Thinking and Exercise Cycle Safety

3.9 Research Studies in Creative Thinking/Brainstorming

In 1950, Guilford wrote of the neglect on the part of psychologists of the subject of creativity. Guilford (1950) analysed the index of Psychological Abstracts for the preceding 23 years and found that only 186 of the 121,000 (or approximately 0.15%) of titles were listed as relating the subject of creativity. Recently, Sternberg and Lubart (1996) conducted a similar analysis of Psychological Abstracts between 1975 and 1994 and found that papers relating to creativity represented approximately 0.5% of the total. This represented something of an increase in the interest in creativity as a proportion of the field of psychology, but Sternberg and Lubart highlighted the relative lack of research about creativity by showing that in the same period studies of *reading skill*, represented 1.5% of the abstracts; three times that of creativity.

Among the relatively small pool of creativity research noted above, only a portion of this research has concentrated centrally on methods for improvement of creativity. While the subject of creative thinking is wider than brainstorming, it's influence has been strong. The discussion that follows thus centres on research that was undertaken following the growth in use of the brainstorming technique. A full description of each of these research studies in a way so as the methodologies and results could be fully understood would impede the reading to a significant extent, therefore the summaries of the following research studies can be found in Appendix A.

3.9.1 The Effect of Brainstorming

Studies on the subject of brainstorming have typically tested the effect of either training in brainstorming versus no training; or tested the effect of encouraging subjects to use the brainstorming instructions versus giving them no such instructions. The subsequent tests have mainly been based on generating alternative ideas in response to a simple problem such as; *find alternative uses for a coat hanger*. Assessment then has typically involved measuring the quantity and quality of the output; a model established by Guilford (1950).

Many studies have shown that *training* in brainstorming lead to improvement on these tests; both in terms of idea fluency and often a measure of the quality of the ideas (Meadow & Parnes 1959; Parnes & Meadow 1959; Parnes 1961; Reese and Parnes 1970; Baer 1988). The magnitude of the changes, where reported, have been in the order of 100% (Parnes & Meadow 1959) and some have been reported to have maintained some years after the training (Parnes & Meadow 1960). While the studies of brainstorming training have usually been confirming of each other, one contrasting study found an increase in the originality, or quality, but no effect in terms of idea fluency (Kabanoff & Bottger 1991).

Further studies, have shown that creative output was improved by encouraging subjects to use brainstorming *instructions* as against emphasising non-brainstorming where subjects were encouraged to be *critical of ideas* (Parnes & Meadow 1959; Meadow, Parnes & Reese 1959; Weisskopf-Joelson & Eliseo 1961; Parloff & Hanson 1964; Sappington & Farrar 1982; Szymanski & Harkins 1992). Where reported the increases in total idea output have been 70% (Parnes & Meadow 1959), 100% (Szymanski & Harkins 1992), 100%-300% (Weisskopf-Joelson & Eliseo 1961) and 450% (Parloff and Hanson 1964) and in terms of good ideas have been between 50% (Sappington and Farrar 1982) and 100% (Meadow, Parnes & Reese 1959; Parloff and Hanson 1964).

Osborn asserted that brainstorming should lead to an increase not only in the number of ideas but also in the quality. The research by Weisskopf-Joelson & Eliseo (1961), Parloff and Hanson (1964), and Szymanski and Harkins (1992) tended to not support Osborn's claims about this relationship. However, Parnes (1961) examined the brainstorming output of individuals and compared the ideas produced at various stages of the brainstorming. Parnes showed that the number of good ideas as a proportion of the total, improved as the brainstorming progresses, thus supporting Osborn's claim.

Osborn's model encouraged thinking in a free-wheeling, anything-is-possible style. In reality, this may be difficult to engender given the relative seriousness of many real-life problems. Some studies have examined the link between the potential end uses of the ideas and the productive output. Sessions that seemed to lead to direct consequences have been shown yield less ideas than when the session seemed to be a training exercise only (Harari & Graham 1975; Maginn & Harris 1980). Further studies have demonstrated that controversial topics lead to less ideas than mundane topics (Harari & Graham 1975; Diehl & Stroebe 1987). These findings show the importance of generating an atmosphere of free-wheeling, but that creating this environment may be difficult depending on the perceived end-uses and seriousness of the issue at hand.

One of the appeals of group work is the possibility that the ideas flowing around can prompt the thinking of individual members. One of Osborn’s claims was that the stimulus of other ideas are an important part of the value of generating ideas in groups. This prompted a number of research studies that isolated this effect to measure if it indeed was important. The studies that have directly examined the effect of idea-stimulus showed that it had no effect (Madsden & Finger 1978; Connolly, Routhieauz & Schneider 1993; Paulus, Dzindolet, Poletes & Camacho 1993). It appears that the supposed value of the stimulation given to individual thinking by the presence of other ideas has not been supported by research. It seems that this is not a particular reason to work in groups.

Criticism is supposed to be withheld in brainstorming. Studies in this area have shown that performance can be reduced with a deliberate increase in the level of criticism (Smith 1993). Direct monitoring of the group's performance has been shown to reduce idea output (Diehl & Stroebe 1987) while another study showed that direct monitoring had an equal effect with video taping and the prospect of later evaluation (Maginn & Harris 1980). There is evidence that criticism reduces performance, however eliminating criticism may be difficult as other work has shown that critical people are perceived as more intelligent and capable (Amabile 1983). While reducing criticism may increase idea production, there are social, ego-based reasons why criticism will be difficult to discourage.

In summary, some studies have investigated training in brainstorming and found it to be effective (Meadow & Parnes 1959; Parnes & Meadow 1959; Parnes 1961; Reese and

Parnes 1970; Baer 1988). Others have examined the effect of encouraging subjects to employ the brainstorming instructions versus non-brainstorming instructions, and found this to be also successful (Parnes & Meadow 1959; Meadow, Parnes & Reese 1959; Weisskopf-Joelson & Eliseo 1961; Parloff & Hanson 1964; Sappington & Farrar 1982; Szymanski & Harkins 1992). Further work has shown that the components of brainstorming are valid by showing that influences like criticism (Smith 1993) or the potential for evaluation (Diehl & Stroebe 1987) have a negative effect on idea productivity. The brainstorming model invites a free-flowing approach to the generation of ideas. Some studies have shown that treating a topic as frivolous has been shown to be beneficial as these types of topics lead to greater brainstorming performance (Harari & Graham 1975; Maginn & Harris 1980; Diehl & Stroebe 1987). Idea-stimulus, however, a key part of the supposed value of group brainstorming, has been shown to have no effect (Madsden & Finger 1978; Connolly, Routhieauz & Schneider 1993; Paulus, Dzindolet, Poletes & Camacho 1993).

While the studies above either investigated brainstorming components or the technique as a whole, a great deal of research interest springing from the brainstorming method has been in the area of the effectiveness of group thinking.

3.9.2 Performance of Nominal Groups versus Interacting Groups

The popularity of brainstorming encouraged group creative thinking. Many studies have since compared group brainstorming with individual brainstorming. To test this, the productivity of nominal groups (the compilation of individual efforts) have often been compared to that of interacting groups. Nominal groups have consistently been more productive. Studies of groups of four have shown that nominal groups were more productive than interacting groups (Taylor, Berry & Block 1958; Bouchard, Barsaloux & Drauden 1974; Harari & Graham 1975; Graham 1977; Maginn & Harris 1980; Jablin 1981; Diehl & Stroebe 1987; Diehl & Stroebe 1991; Thornburg 1991; Stroebe, Diehl & Abakoumkin 1992; Camacho & Paulus 1995; Furnham & Yazdanpanahi 1995; Paulus, Larey & Ortega 1995). Studies with larger groups have shown similar effects and have shown that as group sizes increase these effects become pronounced (Bouchard & Hare

1970; Bouchard, Barsaloux & Drauden 1974). A variant on the typical nominal group research has been studies where interacting groups interacted via a computer rather than in actual contact. Comparison of these electronically interacting groups with regular nominal groups have shown that they yield similar outcomes for groups of up to six or eight participants, while the electronic method has been more effective for larger groups (Dennis & Valacich 1993; Gallupe, Dennis, Cooper, Valacich, Bastianutti & Nunamaker 1992; Valacich, Dennis & Connolly 1994).

While the literature is dominated by studies showing the effectiveness of nominal groups, there have been some studies showing that nominal and interacting groups were similar for a group size of four. Bouchard (1969) found that semi-interacting and nominal groups were similar, however the semi-interacting groups were worked half of the time as nominal groups and half the time interacting. Paulus, Dzindolet, Poletes and Camacho (1993) also found nominal and interacting groups of four to be similar, however this only occurred when comparing nominal groups to interacting groups under the influence of individual assessment. Madsden and Finger (1978) showed that nominal groups only outperformed interacting groups after practice, without the opportunity for practice their performance was similar to the interacting groups.

In groups of two and three the differences have not been so clear. Dyads, or groups of two, have been shown to be equally effective when interacting as when in nominal groups (Thornburg 1991; Furnham & Yazdanpanahi 1995). In groups of three, Street (1974) showed that nominal groups were more effective than interacting groups of three, however both these types of groups were outperformed by interacting groups of two!

In summary, interacting groups of four or more are rarely as productive as nominal groups. Due to the decline in per-person performance in interacting groups, the superiority of nominal groups grows as the group size grows. The performance of interacting groups has actually been shown to not improve as group size was increased from four to seven (Bouchard, Barsaloux & Drauden 1974). In terms of idea quality, nominal groups have sometimes been shown to generate better ideas (Diehl & Stroebe

1991) and sometimes been shown to be no different (Taylor, Berry & Block 1958). The acceptance of ideas, and the ratings of quality has been found to be equally good following nominal group work as following interacting group work (Graham 1977). The superiority of nominal groups has been demonstrated over a variety of brainstorming session lengths (Diehl & Stroebe 1991).

3.9.3 Satisfaction and Perception of Success in Interacting Groups

Through objective comparison of performance, many studies have shown that interacting groups were less effective than nominal groups. Measuring the perception of the subjects however has drawn out the reversed impression. Some studies have questioned subjects about how they perceived the relative performance of the groups. The results have shown a contrast between the actual performance and the perception of performance. Subjects believed that group brainstorming was more enjoyable (Diehl & Stroebe 1991) and more effective (Stroebe, Diehl & Abakoumkin 1992; Paulus, Dzindolet, Poletes & Camacho 1993; Paulus, Larey & Ortega 1995). While the enjoyment is not argued, the effectiveness would seem to be a clear mis-perception. Although only Diehl & Stroebe (1991) measured enjoyment, this factor may explain the perception of effectiveness.

3.9.4 The Reasons for Failure of Interacting Groups

Given the failure of interacting groups to live up to the predictions of Osborn, a number of studies have attempted to extract the factors that inhibit idea generation in interacting groups. Some personality factors such as homogenous personality (Hoffman 1959), apprehension toward communication (Jablin 1981) and social anxiousness (Camacho & Paulus 1995) have been shown to inhibit interacting group brainstorming. The possibilities for the poor performance generally centre on a few themes such as blocking, social loafing and evaluation apprehension. Blocking is the term used to describe the situation where people can't talk when they have an idea because someone else is talking, in the meanwhile they forget their idea, or think it's too similar to another idea, and so on. Social loafing is the phenomenon where an individual's motivation in an interacting group is reduced as the assessment of the performance will be based on the whole group rather than individually. Evaluation apprehension means that individuals may be discouraged from making suggestions as they fear harsh evaluation of their ideas.

Sometimes it has been thought that the effectiveness of interacting brainstorming is affected by the reduced individual responsibility and motivation that comes with having others to provide the ideas. This effect has been known as *social loafing*. Like Sims' (1928) study showing the value of individual motivation in simple mental tasks such as reading, the performance of interacting groups when brainstorming has been shown to be improved with the use of individual assessment (Diehl & Stroebe 1987) and by giving subjects an opportunity to compare their own performance with earlier participants (Szymanski & Harkins 1992). This would indicate some type of individual motivational increase or perhaps goal setting. Latham & Saari (1979) showed that goals increase performance whether self-set or imposed, however Latham and Saari gave no indication of the relationship of goals to performance. Locke (1982) showed that higher goals increase performance, although Locke's study was flawed and Lorenzi (1988) later found that higher goals lead to only slightly higher performance and this was dependant on the incentive of a cash prize, without such an incentive the goal levels had no effect. There seems to be no strong evidence that goal-setting can lead to substantial improvements in the production of ideas. Further studies, investigating the impact of individual assessment, have shown that individual assessment made no difference to the performance of interacting groups (Diehl & Stroebe 1991; Price 1993). The evidence of the existence of social loafing is thus mixed. Mongeau (1993) argued that the group leadership that Osborn emphasised has not been stressed in many studies and that the presence of stronger leadership may impact on the participation of individual group members. Although intuitively attractive, there seems no clear evidence that individual assessment will spur greater motivation and consequently greater group productivity.

In addition to these personality or personal factors, there's been substantial interest in the examination of structural features of group interaction that give nominal groups an advantage. Subjects in nominal groups are not restricted by the contributions of others when adding ideas whereas in interacting groups it is difficult for more than one person to speak at a time. Blocking of ideas has been suggested as a possible reason for the failure of group brainstorming to live up to the perceptions and expectations. Introducing small impediments to the additions of ideas in nominal groups (computer-based) has been shown to reduce the performance of nominal groups. These impediments included a small delay in the keyboard used to add ideas (Gallupe, Cooper, Grisé & Bastianutti 1994); the necessity to add ideas one at a time rather than simultaneously (Gallupe, Cooper, Grisé & Bastianutti 1994; Valacich, Dennis & Connolly 1994; Diehl & Stroebe 1987; Diehl & Stroebe 1991); and the requirement to take turns in adding ideas (Gallupe, Cooper, Grisé & Bastianutti 1994). Diehl and Stroebe (1991) found that the presence of communication between members did not reduce the effectiveness of nominal groups, but the imposition of a speaking order with requirement to self-manage the order severely impeded the performance of nominal groups. It seems that there is reasonable evidence that some of the poor performance in groups is due to the difficulty in communicating and recording ideas.

3.9.5 Studies of the CoRT Program

The CoRT program is named after the Cognitive Research Trust that de Bono established in the United Kingdom in the 1970's. Studies of the CoRT program represent the only substantial body of research that followed de Bono's writing. The objectives of the CoRT program are as follows;

1. *That there be an area in the curriculum where thinking is treated directly in its own right.*
2. *That students come to regard thinking as a skill that can be improved by attention, learning and practice.*
3. *That students come to regard themselves as thinkers.*
4. *That students acquire a set of transferable thinking tools that work well in all situations and all areas of the curriculum. (de Bono 1991a, p. 1)*

The main idea is to treat thinking as a skill in its own right; distinct from information about any subject in particular. This is similar to the way that the skill of talking is independent of the subject matter of the talking. The skill of talking can be applied to any subject area.

The thrust of the CoRT program seems to be to create a similar effect with thinking skills. The CoRT teaching program has been used by school children for about twenty five years. The program is used in several countries and by children of various ages and ability (de Bono 1982; 1991a, 1991b). In a review of the program in the larger sphere of cognitive education Wolfe Mays (1985) commented that there seems to be some evidence that cognitive education of this type can increase ability in judgement, memory, attention and motivation. McPeck (1983) wrote that the CoRT program has received little or no critical attention from philosophers or professional educators, while Resnick (1987) said that while some teachers involved had voiced their opinion, the CoRT program had received little in the way of formal evaluation. However, both prior to 1987 and since that time, some formal evaluations have been reported.

In addition to anecdotal support for the CoRT program (Chance 1986; Melchior, Kaufold and Edwards 1988; Adams 1989), more formal studies (see Appendix A for detail) have revealed an improvement in subjects' ability to generate ideas (Rosenthal, Morrison and Perry 1977; de Bono 1978; Edwards & Baldauf 1982; Ruffels 1986; Edwards & Baldauf 1987; de Sánchez 1987; Eriksson 1990; Edwards 1991). Some of the studies indicated a potential transfer of the skills into improvement in school subjects (Ruffels, 1986; Edwards & Baldauf, 1987; Edwards, 1991). These indications of transfer are tentative and sometimes contradictory. The skills have not been conclusively shown to transfer into problems distant from those in the program itself (Eriksson 1991).

While the studies are all supportive in their nature, they are not without qualifications. For instance Rosenthal, Morrison and Perry (1977) measured the effects of different methods of teaching the techniques rather than the effect of the techniques themselves, while others were only reported in summary (de Bono 1978), lacked a control group (Edwards & Baldauf 1982; Edwards & Baldauf 1987), or included other material, or modified material, in the program (Ruffels 1986; de Sánchez 1987). Bearing these limiting factors in mind, the studies have indicated that the CoRT program has value in improving thinking skills.

3.9.6 Summary Research Studies in Creative Thinking/Brainstorming

In summary the research on brainstorming has shown that in terms of creative production (usually measures of productivity of ideas and quality of ideas); brainstorming instructions and brainstorming training are effective mechanisms. Of the components of brainstorming, the negative role of criticism has been confirmed, although the injection of novel ideas has been shown to have no effect, and working in interacting groups has been shown to be less effective than the combined ability of the individuals alone. The poor performance of groups may be explained at least in part by personality factors such as social anxiousness but more readily on restrictions on the processes of adding ideas. The relationship Osborn predicted between quality and quantity has not been confirmed. Studies of the CoRT program in schools have indicated that these type of techniques may also be effective in terms of enhancing creative thinking.

3.10 Assessment of Creative Thinking

In the 1950's Guilford (1950) suggested that creative output could be considered as being composed of factors such as fluency, flexibility and novelty as well as other factors such as sensitivity to problems and synthesising ability. Since that time creativity has been most often measured in terms of idea fluency (output of ideas) and some measure of idea quality (like originality, novelty or usefulness), such as in the popular Torrance Tests (Torrance 1974). The Torrance Tests were designed for use with school students. The tests present the students with a case study problem. The cases are presented as a picture, or a written description or sometimes both. An example is the test of *unusual uses*.

> *Most people throw their empty cardboard boxes away, but they have thousands of interesting and unusual uses. In the space below and on the next page, list as many of these interesting and unusual uses as you can think of. Do not limit yourself to any one size of box. You may use as many boxes as you like. Do not limit yourself to the uses you have seen or heard about; think of as many possible new uses as you can. (Torrance 1974, p. 10)*

The time for students to attempt the tasks ranged from five minutes to ten minutes. Responses are scored against three main measures.

1. Fluency: The number of relevant ideas.
2. Flexibility: A measure of the breadth of ideas (by allocating ideas to standard categories)
3. Originality: A measure of the originality of the ideas. This is measured against a standard set of ideas. Based on past use of the tests with 500 subjects Torrance made lists of potential ideas and then dived the list into three categories according to their commonness. Ideas that were less often suggested were rated as more original.

The Torrance Tests for creative thinking are the most widely cited standardised test of creative thinking (Shaughnessy 1995). While many researchers have used their own assessment techniques, these have usually been based around a similar measurement such as *idea quantity* and *idea quality*. This methodology has been extremely common throughout studies of creativity. Among the research cited in this thesis almost all have used these factors in their assessment of creativity. Cooper (1991) added that the Torrance Tests have significant validity and reliability although could benefit from some updating in the breadth of creativity that is considered and some revision of materials. Polland (1994) argued that relying on Guilford’s components of creativity (fluency, flexibility and originality) is far from ideal and suggested that the originality classifications are subjective and can too easily classify ideas as un-original. Polland says that *...the Torrance Tests call for responses to questions for which they already have too many answers.*’ (Polland 1994, p. 14). While not suggesting an alternative way to measure creativity, Polland put forward the proposal that creativity is personal and depends heavily of the motivation and personal interest of the subject and that output can be creative for one and not creative for someone else. While there are some detractors, Guilford’s model is yet to be replaced as a methodology for the assessment of creative output.

3.11 Creative Thinking: Summary

Historically there have been some difficulties with the study of creative thinking by examining people who were very creative. This has been limiting as it implied the role of natural talent. More fruitful gain has been made with the strong recognition by psychologists early this century of the problem of the *uncreative mind*. It is thought that the best functions of the mind, such as recognition and repetition, simultaneously inhibit the generation of new ideas. By studying past creative moments it has become apparent that there were often serendipitious events that provided a turning point in the thinking of those involved. Consequently it has become common to suggest that more of these fortuitous events can be deliberately generated by the use of specific techniques that widen the potential domain of solutions to a problem. Some of the simplest involve just searching for alternatives, or gathering a group of people to do the same, thus relying on different viewpoints, and the possibility of combination. These methods might often be sufficient. More formal methods involve active divergent thinking or deliberately challenging current assumptions. The techniques can be summarised into three main areas (Table 3-7). The first designed to create a creative climate, the second to force relationships between an element of the problem at hand and an introduced idea, and the third group of techniques are based on altering perception of a problem domain by challenging current assumptions. To these we could add a fourth set of techniques that aim to broaden of thinking such as Gardner's multiple intelligences model, the techniques of mind mapping and so on.

Techniques of Active Divergent Thinking		
Creative Climate	***Forcing Relationships***	***Breaking the Boundaries***
• *Separate Idea Generation and Analysis* • *Exclude Criticism*	• *Morphology* • *Analogy* • *Substitution* • *Combination* • *Random Word*	• *Magnify* • *Exaggerate* • *Minify* • *Modify* • *Re-arrange* • *Reverse, Challenge* • ***Hierarchy of Control***

Table 3-7 Techniques of Active Divergent Thinking

Importantly the most apparent technique to be added is the *hierarchy of control*, a technique of active divergent thinking for safety improvement. In safety there is a continuing need to develop new approaches to risk control and thus creative thinking would seem to be relevant. The specific techniques share strong parallels. The example shown above of the exercise cycles showed that the hierarchy of control is functionally much the same as many tools in creative thinking. The high-order steps in the hierarchy attempt to shift thinking outside the boundaries of the current paradigm.

Weisberg and Alba (1981) demonstrated an important lesson in creative thinking that will be also relevant in the application of creative thinking to safety. They showed that breaking the assumed boundary in the nine-dot problem, while integral to the ultimate solution, was not an instant pathway to the solution. Similarly, the mechanisms of creativity or the hierarchy of control, rarely lead to immediately elegant solutions. More often the techniques of active divergent thinking (such as *elimination*) don't make any sense. Therefore, there needs to be a period of manipulation to see if the idea can be made to work, or to see what other ideas can be developed as a result. The value of active divergent thinking may often be only realised with some manipulation of the ideas. Should critical thinking be brought to bear on the process too early then its likely that the thinking will move back *inside the square*. Thus active divergent thinking usually has to be followed by some effort to *manipulate* and improve the ideas put forward by these processes because it is likely that they will not immediately make sense. Their true value will only be realised by some consideration of the possibilities that they propose. This is why the creative climate is important. Nevertheless, the movement outside the square gained potentially through the techniques described as active divergent thinking remains the pivot to the creative process. Finally, Charles Darwin:

> *The Imagination is one of the highest prerogatives of man. By this faculty he unites former images and ideas, independently of the will, and thus creates brilliant and novel results. (Darwin 1952 (orig. 1871), p. 292)*

Chapter Four

Methodology

4. Methodology

4.1 Hypothesis

Control at source and the *hierarchy of control* are the basis for preventative measures required by occupational health and safety legislation in Australia and internationally. The hierarchy typically extends from a priority of controlling hazards at their source, to less dependable measures such as those that relying on safe behaviour. The high order controls demand hazard elimination or controls that do not rely unduly on the appropriate behaviour of those at risk. This approach can be described as the *safe place* philosophy.

The safe place principle implies that safety is best incorporated at the design stage. Given their influence over design, the education of engineers in the principles of safety has been seen for some time as a priority and some universities have integrated safety topics with engineering studies. In addition there have been efforts at wider integration of safety and engineering such as those by NIOSH (USA) and the NOHSC (Australia). The desirable integration of safety with engineering education has been difficult due to already crowded engineering curricula. The challenge therefore was to develop an innovative way to improve the ability of engineers to develop safe place solutions to safety problems.

The hypothesis is that training in creative thinking methods will improve the ability of engineers to develop safe place solutions to safety problems. Part of the reasoning behind this hypothesis was that the thinking needed to apply the *hierarchy of control* shares a strong relationship with the principles of creative thinking. The preferred controls direct attention toward *elimination* of the hazard. The safe place thinking therefore challenges the established ways of doing things and demands a rethinking of assumptions, a re-examination of the process of work. Techniques for creative thinking often aim toward similar ideals; that is, to escape from dominant paradigms and generate thinking that is *outside the boundaries*. For this reason it seemed likely that creative thinking may facilitate the safe place approach to prevention. The potential for employing creative thinking in prevention exists within a climate of a growing emphasis on creative thinking as an issue of wider industrial relevance.

Hypothesis: The hypothesis is that training in creative thinking methods would be an effective way to improve the ability of engineers to design for safety.

4.2 Development of Testing Tools

Training programs have often been evaluated by measuring the *subjective* usefulness of the training and quality of presentation. However, as Hale (1984) pointed out, rarely have training programs been evaluated in terms of their impact on *performance*.

There seems to be little available in terms of a general test to measure the ability to solve safety problems. The *Mental Measurements Yearbooks*, published by the University of Nebraska Press, list tests of mental abilities. The ninth yearbook (Mitchell 1985) listed 1409 various tests, but only a few of these had any relevance to safety. A few tests (four) of trade competence mentioned safety, while one test, the *Supervisory Inventory on Safety* developed by Kirkpatrick, specifically addressed the issue. Despite writing to the author I have not been able to obtain this test. The only review was not complementary and suggested that the use of the test is not justified (Carbonell 1985).

Among a total of 477 tests, the Eleventh Yearbook, listed one further test with relevance to safety; the *Supervisory Job Safety*, published by Organizational Tests Limited. The summary said that the purpose of the test is to '*Measure "knowledge of and attitudes toward safety practices."'* (Kramer & Conoley 1992). The test consisted of 80 questions to be answered true or false. The test was first written in 1970, however I purchased a recent copy. The test seems to be based on the unsafe act/unsafe condition model and unfortunately emphasises the *safe person* philosophy. For instance, according to the test the following statements are true;

- *Physical or mental inadequacy often produce unsafe practices.*
- *Unless 'unsafe practices' are detected early, they tend to become strongly entrenched work habits.*

- *One sound reason for employee medical examinations is to match employee physical abilities to the requirements of the job.*
- *'Unsafe practices' most often develop from faulty initial instruction.*
- *Every unsafe act should be corrected immediately.*
- *A good way to minimize accidents is to eliminate unsafe acts.*
- *Keeping the back as straight as possible when lifting heavy objects will usually avoid injuries.*
- *Women workers should be required to wear caps or hair nets to prevent hair being caught in moving parts of machines.*

(A Sample of 'True' Statements from the Supervisory Job Safety Test, Organizational Tests Limited 1970)

The *Supervisory Job Safety Test* does not reflect the type of thinking sought in prevention efforts today, and consequently would not be a suitable measure. For this project, the key was to evaluate the effectiveness of the training intervention in terms of its effect on the way that subjects would design for safety. Many studies of creative performance have employed a methodology of presenting subjects with a case study problem, allowing a limited time for solutions, and then assessing the performance by measuring the number of solutions (fluency) and very often by taking a measure of the quality of the ideas such as originality. This model stemmed from the methodology suggested by Guilford in 1950 and seems widely accepted.

Given the absence of a suitable testing tool for creative thinking in accident prevention, a new tool was developed to measure the success of the training (Appendix B). The methodology employed was that widely used in studies of creative thinking but customised to field of safety. A series of fictional accident case studies were developed (Table 4-1). Subjects completed half the tasks individually and half in teams. Half the tasks involved the generation of solutions for which six minutes per case was allowed and half involved the prioritization (ranking) of six potential solutions to a case study problem, for which 2.5 minutes was allowed.

Case	Title	*"Team"* Size	Task
1.	Grain Worker and the Rail Carriage	N	Generate Solutions
2.	Lawyer and the Coconut Tree	N	Generate Solutions
3.	Motorist and the Car	N	Generate Solutions
4.	Sawyer and the Circular Saw	NNN	Generate Solutions
5.	Mining Supervisor and the Dump Truck	NNN	Generate Solutions
6.	Bank Manager and the Chain Saw	NNN	Generate Solutions
7.	Aircraft Fitter and Tug	N	Prioritize Solutions
8.	Gardener and the Gang Mower	N	Prioritize Solutions
9.	Cable Laying Contractor and the Bogged Utility	N	Prioritize Solutions
10.	Orchardist and the Power Line	NNN	Prioritize Solutions
11.	Transport Worker and the Falling Pipes	NNN	Prioritize Solutions
12.	Production Engineer and the Forklift	NNN	Prioritize Solutions

Table 4-1 Case Studies and Tasks

From this data collection, three variables of interest were drawn;

1. Generation of Solutions (Number)
2. Generation of Solutions (Quality: Proportion Safe Place)
3. Prioritization of Solutions (Correlation of Ranking with Standard Ranking)

4.2.1 Generation of Solutions (Number)

For cases one to six subjects were required to suggest *risk control solutions*. Cases one, two and three were completed individually and cases four, five and six completed working as a team of three people. This variable was evaluated by simply counting the number of solutions generated by each subject, or team.

4.2.2 Generation of Solutions (Quality: Proportion Safe Place)

The assessment of the quality of the solutions was based a measure of the extent to which solutions were nearer to the safe place or nearer to the safe person philosophy. To measure this, test responses were classified into these two categories according to a standard classification developed for this purpose. For each case a list of potential solutions was split into the *safe place* and *safe person* categories (Appendix C). This list provided standard way to classify each solution to then calculate the proportion of safe place solutions among a set of ideas from one subject, or from one team.

4.2.3 Prioritization of Solutions (Correlation of Ranking with Standard Ranking)

A further task was introduced which has not been common in studies of creative thinking. The purpose was to test the ability to prioritize solutions once they have been developed. This is known sometimes as convergent production (Guilford 1950) and has been described as the natural progression from creative efforts (Osborn 1948). However, given that this factor is not a central part of creative production, it has subsequently not been a strong feature of the assessment of creative thinking programs. While the generation of control options is important there comes as stage where a decision must be made as to which of the control alternatives are the best. Quality decision making skills are clearly important in health and safety; it must be clear what types of solutions are likely to be successful. Therefore the second part of the test (Book Two, Appendix B) was based on the prioritization of control options for a given case study in terms of their preventative potential. The prioritization variable was the Spearman correlation of each subject's (or each team's) ranking with a standard optimum ranking. The standard ranking was validated by expert opinion (Appendix C).

4.2.4 Summary of Variables

In summary, the testing tools consisted of two main tasks; generating safety solutions and prioritizing safety solutions. Subjects worked on half the cases individually and half as teams. The test was carried out in the order that the cases are numbered (Table 4-1).

4.3 Training Interventions

4.3.1 Creative Thinking Training

4.3.1.1 Rationale for the Choice of the Six Thinking Hats Program

The creative thinking training consisted of the six thinking hats program (de Bono 1985). The reasons for this choice were as follows.

Altering perception or *breaking out of the box* is a key element of creativity. The six hats technique embodies this principle and includes divergent thinking tools.

It's widely believed that judgement and criticism are harmful to creative thinking but keeping this type of thinking at bay is difficult. The six hats model encourages concentration on one type of thinking at a time. Potentially this facilitates the exclusion of criticism from creative thinking time.

For individuals to focus on a certain type of thinking it would seem logical that they must appreciate where that thinking fits in a larger framework (metacognition). The six hats encourages the organisation of thinking thus facilitating this metacognitive approach.

While the effectiveness of team thinking may be questionable it is undeniable that the role of teams represents a major influence in working and social life. Despite the failure of team work in many experimental situations, their association with creativity is strong and it seemed wise that experiments should be carried out in both individual and team settings. The six thinking hats model lends itself to individual and team thinking.

Gordon (1961) said that models for creative thinking are useless if they are not simple. Simplicity is one of the hallmarks of the six thinking hats method. The rules are easy to remember and so instructions are usually unnecessary.

Overall the six thinking hats model provides a mechanism for creative thinking that is simple, portable and embodies principles of creative thinking. Furthermore while brainstorming has been studied widely, other techniques like the six thinking hats model have not been researched so thoroughly. As an indication of the potential usefulness, the studies of de Bono's CoRT program for schools have been positive about the program's value (for example; de Sánchez 1987; Eriksson 1990; Edwards 1991).

4.3.1.2 Accreditation and Training Delivery Format

Advanced Practical Thinking Training (APTT) of Des Moines, USA, administer the certification of trainers and the six thinking hats training materials. In November 1993 I attended a four-day trainer's certification session in Toronto lead by de Bono.

APTT supported this research by supplying the necessary training materials for the research. In return for this support they are to receive a copy of this thesis. APTT have made no attempt to influence the design of the research in any way.

There were two versions of the training materials provided; the *Short Course* and *Full Course*. The longer course is essentially the same but includes more exercises. The project involved a mixture of these manuals, however all of the training was a similar duration (about one day) and covered the same topics (see below). The Technology Students' training was about ten to twelve hours in five sessions over a five weeks while the training for all other groups was completed in one day. The topics covered in the training included;

- The nature and history of creative thinking
- The roles of argument and critical thinking
- Overview of the six thinking hats
- Developing skills in each hat
- Switching thinking by switching hats
- Developing sequences of hats
- Using the hats individually or conversationally
- Using the hats in formal meetings
- Note: No safety information at all was included

The key dot-point was perhaps the last one. The purpose of the exercise was to examine the effectiveness of a creative thinking training program on safety design ability. Obviously the inclusion of any safety examples would have compromised the study and so the topic of safety was positively excluded from the training. No safety examples, stories, exercises, etcetera of any kind were used in the training.

4.3.2 Hazard Management Training

The hazard management training, used in only one part of the study, was conducted by VIOSH-Australia over two days and involved an interactive style of learning that included case studies. The training emphasised many of the ideas discussed in Chapter 2, such as;

1. Energy damage concept.
2. Hierarchy of controls.
3. Safe Place concept.
4. Risk management (identification, assessment and control).

4.4 Subjects for the Research

The focus of this writing has been engineers, given their impact on the design of workplaces. There are clearly other groups who influence the design of workplaces and consequently other groups were included. There were four study groups in the research; three groups of students of the University of Ballarat and a group of government safety advisers. All subjects participated voluntarily.

1. Engineering Students
2. Technology Students
3. Industry Safety Advisers
4. Government Safety Advisers.

4.4.1 Engineering Students

The engineering students were fourth year Bachelor of Engineering students at the University of Ballarat. They were recruited by letter and participation was voluntary. Forty-two students participated in the research on the 3 September 1994.

These students had been exposed to health and safety education, mainly through third-year *Engineering Management* and fourth-year *Environmental Principles* (University of Ballarat 1994). Engineering Management consisted of three hours per week for the entire third year with health and safety comprising 25% of the content. Environmental Principles consisted of four hours per week for the entire fourth year. Approximately 60% of the total, and 100% of first semester, was devoted to occupational health and safety.

The student engineers were mid-way through fourth year and therefore had completed their exposure to health and safety. Formal contact had been about three hours per week for half a semester in third year and four hours per week for a semester in fourth year.

4.4.2 Technology Students

The technology students were first-year Bachelor of Technology students of the University of Ballarat. Eighteen students participated in the research over the first five weeks of second semester, 1994. The first semester of this course included no studies in safety.

4.4.3 Industry Safety Advisers

The industry safety advisers (referred to from here on as *industry advisers*) were students of the Graduate Diploma in Occupational Hazard Management at the University of Ballarat. This course operates by block mode over two years. The students who volunteered were a mixture of first and second year students, who in the main were working full-time as health and safety practitioners. Forty-eight industry advisers participated in the research during the mid-year, on-campus session, on 9 July 1994. First year students had completed one semester of the Graduate Diploma and the second year students had completed three semesters. This group had the benefit of extensive experience in occupational health and safety. Many in this group had bachelor's degrees and as mentioned all had partially completed a tertiary course in occupational health and safety.

4.4.4 Government Safety Advisers

The government safety advisers (referred to as *government advisers*) were a group of people who work for a state government organisation. Their professional role was mainly as advisers to industry about health and safety. Mainly the subjects were trade qualified with between five and ten years experience in this job. This group was specialised and experienced in safety. Their formal training had typically consisted of in-house short courses rather than formal tertiary education. One hundred and forty-six government advisers participated in the research on 9 June 1995.

4.5 Experimental Design

The training was evaluated by comparing the performance of untrained subjects with that of trained subjects. The only exception being the study with the technology students, where subjects were pre and post-tested in a paired design. Table 4-1 shows the broad experimental design while Figure 4-1, Figure 4-2, Figure 4-3 and Figure 4-4 show the procedures involved with each group of subjects. Subjects fell into either the untrained or trained groups by random selection from alphabetical lists of subject names.

Subjects	***Treatment***	***Type of Design***
Engineering Students (N=42)	*Creative Thinking Training*	*Untrained (N=21) v Trained (N=21)*
Technology Students (N=18)	*Creative Thinking Training*	*Pre-test (N=15) v Post-test (N=12)*
Industry Advisers (N=48)	*Creative Thinking Training*	*Untrained (N=24) v Trained (N=24)*
Government Advisers (N=146)	*1. Creative Thinking Training*	*Untrained (N=15) v Trained (N=19)*
	2. Hazard Management Training	*Untrained (N=15) v Trained (N=112)*
		HM Trained (N=112) v CT Trained (N=19)
	3. Combined (1&2)	

Table 4-2 Treatments and Experimental Design

4.6 Statistical Analysis

Statistical analysis was carried out on the effects of the treatment and the differences between the four study groups on the three key response variables.

1. Generation of Solutions (Number)
2. Generation of Solutions (Quality: Proportion Safe Place)
3. Prioritization of Solutions (Correlation of Ranking with Standard Ranking)

4.6.1 Independent Samples and Related Samples

As Table 4-2 shows the research mainly involved testing independent untrained and trained groups of subjects (engineers, industry advisers and government advisers). In the case of the technology students the samples were related and so paired analysis (for individual subjects) was employed. To account for the possible effect of practice upon repeating the tests a second time in the trained condition, the technology students were tested untrained (pretest1) and then tested again one week later after no training (pretest2) before completing the training and again completing the test about five weeks later. The practice effect was thus analysed by comparing the second pretest with the first while the treatment effect was analysed by comparing the trained test with the second pretest. In the case of the technology students working in teams, no statistical tests of significance could be performed as the composition of the teams changed over the term of the study.

4.6.2 Generating Alternative Solutions

These are *count* type data. The variable potentially ranges from zero to infinity on a discrete ratio scale. For the comparison of two independent samples (engineers, industry advisers and government advisers) the test used was the independent samples t-test. For comparison of two related samples (technology students) the test used was the paired t-test. Analysis of variance was used for the comparison of multiple independent samples (comparison of the groups).

The assumptions of the t-test are normality and equality of variance within each group, although the t-test is known to be robust to violation of these assumptions (Kendell &

Stuart 1979). Tests of normality using the Kolmogorov-Smirnov (Kendell & Stuart 1979) and Shapiro-Wilks (Kendell & Stuart 1979) tests were conducted (Table 4-4). The more significant result of these two tests is reported in each case. The analysis shows that the data representing the number of alternative solutions have a reasonable level of normality and therefore the t-test is appropriate. An enhanced level of normality would be desirable though and the often used square root ($X'=\sqrt{X}$) normalising transformation (Snedecor & Cochran 1967) and also the log ($X'=\ln X$) transformation (Snedecor & Cochran 1967) were trialed but made little improvement (detail of this is not reported). The t-test is sensitive to equality of variance. Levene's test of equality of variance (Neter, Kutner, Nachtsheim & Wasserman 1996) was conducted and where appropriate the t-test for non-equal variance was employed and is noted where necessary throughout subsequent reporting of the analyses in Chapter 5.

4.6.3 Generating Effective Solutions

In their raw form these data are counts (similar to above) when they represent the number of safe-place solutions. A statistical analysis was performed on these data and reported briefly (see section 5.2.7) however the most important measure of the quality of solutions was the proportion of the total solutions that these good solutions represent. These are then *proportions* type data. The variable thus ranges between zero and one on a continuous ratio scale. For the comparison of independent and related samples the tests used were the same as those for the *number of solutions* variable described above. The normalising transform appropriate should the data be non-normal is the arcsin ($X'=\arcsin(\sqrt{X})$) transformation (Snedecor & Cochran 1967) however tests of normality (Table 4-4) revealed that no transformation was necessary.

4.6.4 Prioritizing Effective Solutions

These data are ordinal data in the raw form. However the variables analysed were Spearman correlation coefficients that range from -1 to +1 on a scale of interval quality. A t-test could be used however the tests of normality revealed poor normality (Table 4-4). The Fisher ($z=0.5\ln((1+r)/(1-r))$) normalising transformation commonly used for Pearson correlation coefficients (Kendall, Stuart & Ord 1987) is not appropriate for the Spearman coefficients in this case due to the occurrence of the extreme values (-1 and +1) which result in meaningless transformations. Therefore, a non-parametric test (the Mann-Whitney U test) was used for the comparison of independent samples (engineers, industry advisers and government advisers). An alternative would have been the Kolmogorov-Smirnov test, however as a direct test of centrality the Mann-Whitney (M-W) U test is more appropriate (Siegel & Castellan 1988). For comparison of related samples (technology students) the test employed was the non-parametric Paired Wilcoxon test. The non-parametric Kruskal-Wallis (K-W) ANOVA (Siegel & Castellan 1988) was used for the comparison of multiple independent samples (comparison of the groups).

4.6.5 Directional Tests

Previous research in creative thinking and the likely link between creative thinking and the control of safety problems lead to the hypothesis that the treatment would enhance performance on the development of solutions. Given that the treatment chosen is a broad thinking enhancement program (as well as creative in intent) improvement was also predicted on the prioritization tasks. For these reasons, directional (one tailed) tests were used. The adopted level of significance was 5% (the actual test results are reported).

4.6.6 Summary of the Statistical Tests Employed

Table 4-3 summarises the statistical tests employed in the data analysis. All statistical analysis was carried out using SPSS for Windows: Release 6.1.3 (Norušis 1995).

Variable	***Two Samples***		***Multiple Samples***
	Independent	***Related***	***Independent***
1. Number of Alternative Solutions	*t-test*	*Paired t-test*	*ANOVA*
2. Proportion of Safe Place Solutions	*t-test*	*Paired t-test*	*ANOVA*
3. Correlation with Optimum Rank	*M-W test*	*Paired Wilcoxon*	*K-W ANOVA*

Table 4-3 Summary of the Statistical Tests Employed

4.6.7 Tests of Normality

Table 4-4 shows the summary results of tests of normality (Kolmogorov-Smirnov and Shapiro-Wilks) conducted on the variables used for analysis as mentioned above in Sections 4.6.2, 4.6.3 and 4.6.4.

Tests of Normality

Case	Tech.			Eng.		Ind.		Gov.					
	Pre1	Pre2	CT	U	CT	U	CT	U	CT	HM	CT+HM[1]	CT+HM[2]	CT+HM[3]
Variable: Number of Alternative Solutions													
One				*ks			* ks						
Two						*** ks	* ks						
Three	*** ks					*sw			** ks	*** ks	* ks		
Four						*** ks							
Five							* ks						
Six													
Variable: Number of Safe Place Solutions													
One	**sw			*ks		*ks							
Two				*sw		***ks							
Three				***ks			*sw			***ks			
Four				*ks									
Five				*ks									
Six						*sw							
Variable: Proportion of Safe Place Solutions													
One	**sw	*sw	*sw										
Two	*sw					**sw							
Three	*sw										**sw		
Four													
Five												*sw	
Six													
Variable: Correlation of Solution Ranks													
Seven	*sw			***ks	**sw		**sw			*ks	**sw		
Eight						**ks	**sw	*sw	**sw	***ks	**sw		
Nine			*ks	*sw	**sw	**sw	***ks	*sw	*sw	*ks	**sw		
Ten				*ks	*sw	**sw	**ks			**ks		**sw	***ks
Eleven							**sw			**sw		**sw	**sw
Twelve							**sw	*sw		**ks	*sw	**sw	**sw

Table 4-4 Tests of Normality Showing Significance Levels Based on the Kolmogorov-Smirnov and Shapiro-Wilks Tests
Note: The significance level shown is the more significant of the two tests in each case
ks: Kolmogorov-Smirnov test
sw: Shapiro-Wilks test
(*/**/***) Statistically significant at 0.05/0.01/0.001 level
Blank Cells: Not Significant
U: Untrained
1: One Team Member Creative Thinking Trained
2: All Team Members Creative Thinking Trained
3: At Least One Team Member Creative Thinking Trained (1&2)
Shaded Sections: Not Applicable

4.7 Methodology Summary

The purpose was to design a methodology to test the hypothesis, including selecting a technique for implementation and developing a means of assessing safety design ability as the result of training in creative thinking.

The main intervention was a creative thinking training program; the six thinking hats program. Training in hazard management was also evaluated in one part of the research as the opportunity was available to compare this training with the same group of subjects who were involved in the creative thinking training.

The method of assessment was like past studies of creative thinking but adapted to the special outcomes sought in safe design. The following variables were considered.

1. The generation of alternative safety solutions.
2. The generation of effective safety solutions.
3. The prioritization of safety solutions.

The subjects chosen for involvement consisted of fourth-year undergraduate engineering students, first-year undergraduate technology students, practicing industry safety advisers, and government safety advisers. The selection of a wider group than engineers was due to the recognition that many groups contribute to safe design. The inclusion of this range of subjects also allowed a comparison of the abilities of subjects with varying safety expertise. All groups were involved in the training of central interest (creative thinking) while the training in hazard management was with the government advisers only.

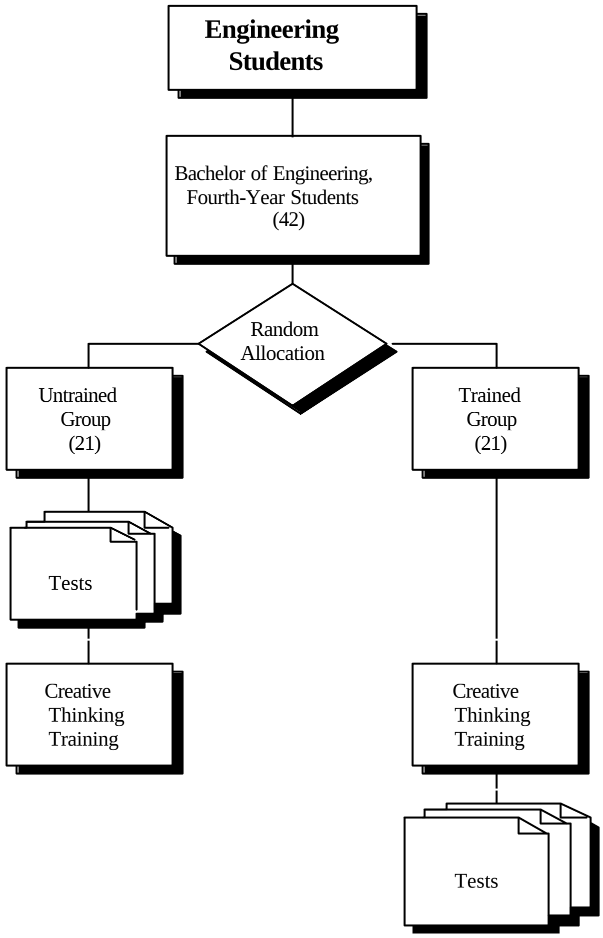


Figure 4-1 Procedure Outline: Engineering Students

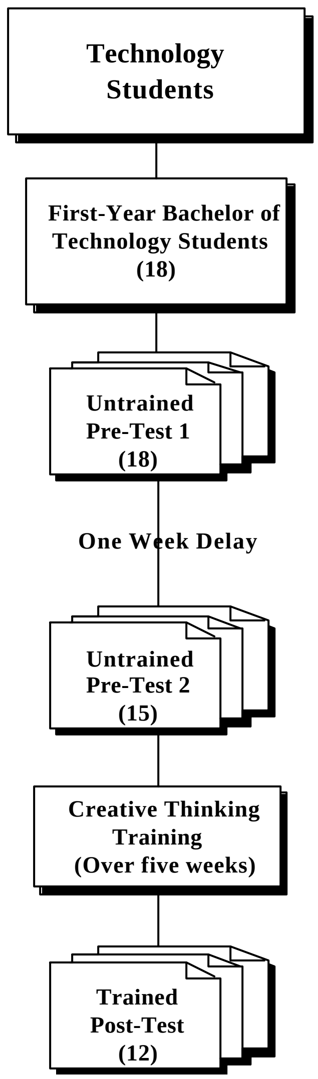


Figure 4-2 Procedure Outline: Technology Students

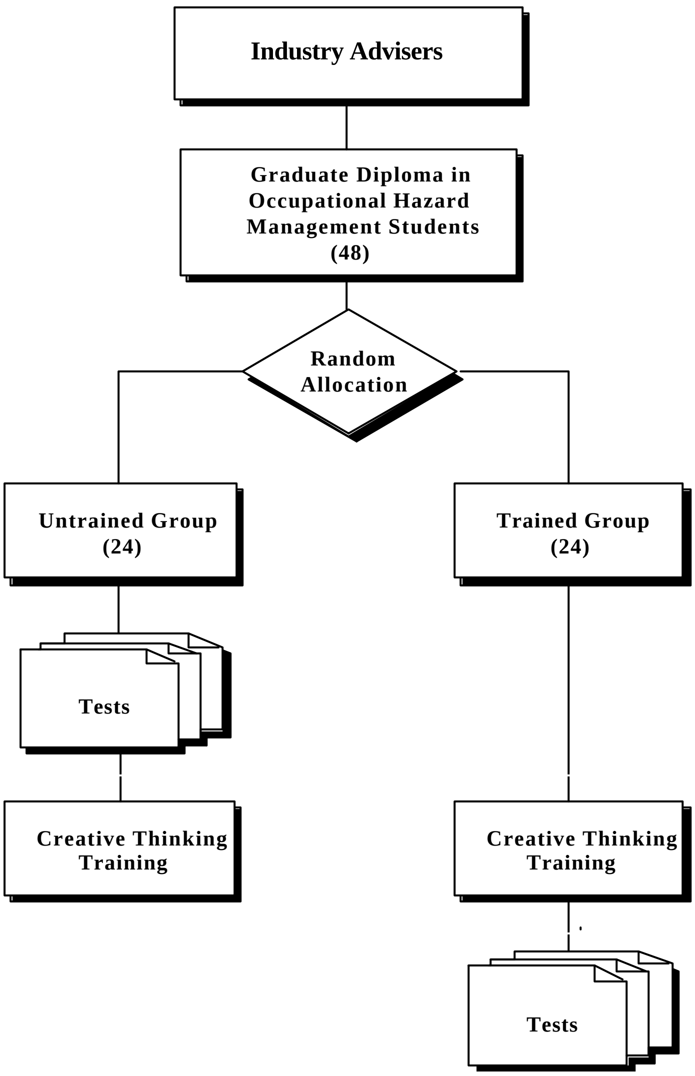


Figure 4-3 Procedure Outline: Industry Advisers

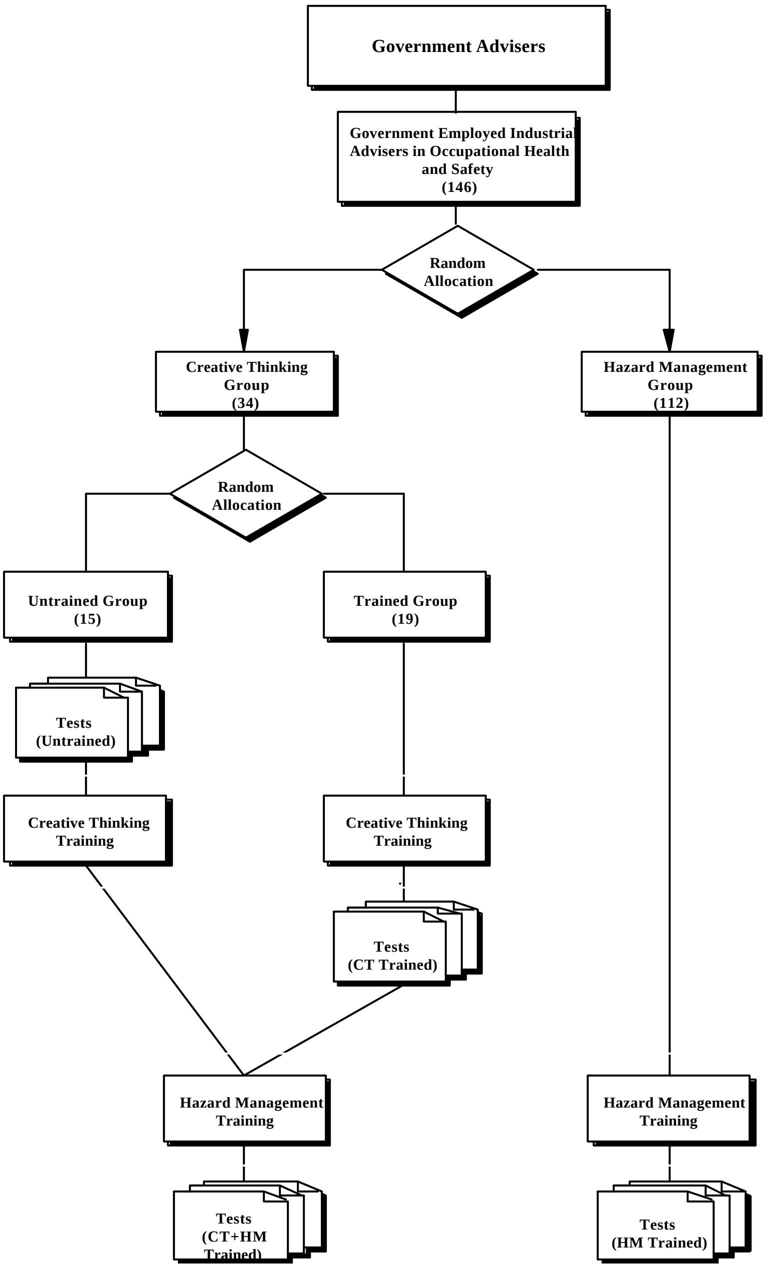


Figure 4-4 Procedure Outline: Government Advisers

Chapter Five

Results

5. Results

This study involved four groups of subjects (engineering students, technology students, industry advisers, and government advisers) and two training interventions (creative thinking training and hazard management training). The data in the raw form are tabulated in Appendix D. Out of these data come a number of comparisons of interest; the main being the effect of creative thinking training, across all groups of subjects, in terms of the three main variables; generating alternative solutions, generating effective (safe place) solutions, and prioritizing effective solutions. The effects of the hazard management training with the government advisers is included. The last section shows the comparison of the different groups of subjects that participated in the study (novice/expert effects). Given that the education of engineers has been a priority issue it is of interest to know how undergraduate students compare with groups of people who are experienced and educated in safety. This might give an indication of the type of improvement that may be achieved should engineers have considerable safety education. Some abbreviations used in this chapter are noted in Table 5-1.

Abbreviation	***Meaning***
Ind	*Industry Advisers*
Gov	*Government Advisers*
Eng	*Engineering Students*
Tech	*Technology Students*
CT	*Creative Thinking*
HM	*Hazard Management*

Table 5-1 Abbreviations

5.1 Generating Alternative Solutions (Number of Alternative Solutions)

One of the key variables measured was the generation of alternative solutions to the case study problems. Subjects worked individually on cases one, two and three and they worked in teams on cases four, five and six. The data that follows are organised according to the four subject groups. A summary of the results then follows.

5.1.1 Engineering Students Generating Alternative Solutions

Case	Mode	Untrained			Trained			t-test	
		N	Mean	SD	N	Mean	SD	t	p
One	Individual	21	4.9	1.8	21	9.0	2.9	t(40)=5.45	<0.001
Two	Individual	21	4.9	2.2	21	11.9	3.8	t(32)=7.44u	<0.001
Three	Individual	21	4.4	1.7	21	11.3	4.4	t(40)=6.54u	<0.001
Four	Team	7	7.3	2.7	7	15.4	3.9	t(12)=4.54	<0.001
Five	Team	7	7.9	2.6	7	17.3	3.1	t(12)=6.16	<0.001
Six	Team	7	7.6	3.0	7	19.1	6.5	t(8.5)=4.24u	0.001

Table 5-2 Number of Alternative Solutions to Safety Problems Generated by Engineering Students: Untrained and Trained
(u) Unequal-variance t-test due to significant Levene's test for Equal Variance

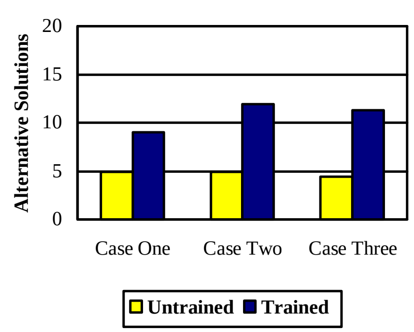


Figure 5-1 Number of Alternative Solutions to Safety Problems Generated by Engineering Students Individually: Untrained and Trained

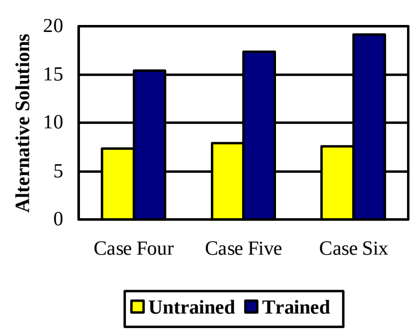


Figure 5-2 Number of Alternative Solutions to Safety Problems Generated by Engineering Students in Teams: Untrained and Trained

5.1.2 Technology Students Generating Alternative Solutions Individually

Case	Condition	N	Mean	SD	Δ	SD	t	p
One	Pretest1	18	4.9	1.8				
	Pretest2	15	6.7	2.3				
	Trained	13	11.9	4.4				
Paired t-test	Pretest1 / Pretest2	15	4.9 / 6.7	1.7 / 2.3	+1.9	1.1	6.82	<0.001
Paired t-test	Pretest2 / Trained	12	7.1 / 11.8	2.4 / 4.5	+4.7	3.7	4.40	<0.001
Two	Pretest1	18	4.8	2.3				
	Pretest2	15	5.6	2.2				
	Trained	13	11.7	4.8				
	Trained (3 Months)	13	13.1	5.3				
Paired t-test	Pretest1 / Pretest2	15	4.6 / 5.6	2.4 / 2.2	+1.0	1.7	2.24	0.021
Paired t-test	Pretest2 / Trained	12	6.0 / 11.8	3.2 / 5.3	+5.8	4.7	4.28	<0.001
Paired t-test	Trained / Trained (3M)	11	12.9 / 14.4	4.4 / 4.6	+1.5	3.1	1.54	0.078
Three	Pretest1	18	5.1	1.9				
	Pretest2	15	5.7	2.0				
	Trained	13	11.7	4.8				
Paired t-test	Pretest1 / Pretest2	15	5.1 / 5.7	2.1 / 2.0	+0.5	2.0	1.02	0.163
Paired t-test	Pretest2 / Trained	12	5.9 / 11.4	1.9 / 4.9	+5.5	4.2	4.55	<0.001

Table 5-3 Number of Alternative Solutions to Safety Problems Generated by Technology Students Individually: Untrained (Pretest1 and Pretest2) and Trained

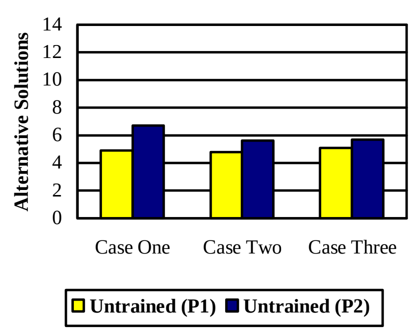


Figure 5-3 Number of Alternative Solutions to Safety Problems Generated by Technology Students Individually: Untrained (Pretest1 and Pretest2)

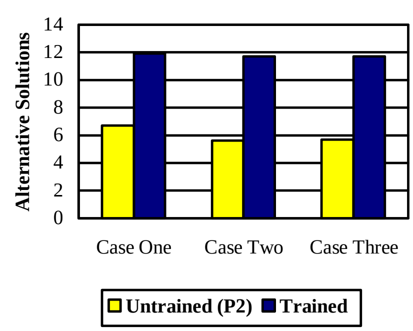


Figure 5-4 Number of Alternative Solutions to Safety Problems Generated by Technology Students Individually: Untrained (Pretest2) and Trained

5.1.3 Technology Students Generating Alternative Solutions in Teams

Case	Mode	Condition	N	Mean	SD
Four	Team	Pretest1	5	8.2	2.59
		Pretest2	5	9.2	2.86
		Trained	5	18.4	3.78
Five	Team	Pretest1	5	7.6	3.78
		Pretest2	5	8.4	2.70
		Trained	5	17.4	3.29
Six	Team	Pretest1	5	7.4	3.51
		Pretest2	5	8.4	2.07
		Trained	5	16.8	3.35
		Trained (3-Month)	5	22.2	2.36

Table 5-4 Number of Alternative Solutions to Safety Problems Generated by Technology Students in Teams: Untrained (Pretest1 and Pretest2) and Trained
Note: No statistical test performed as data is dependent and not-paired

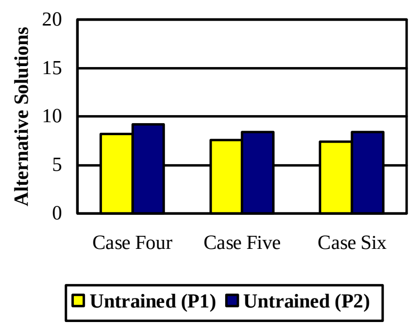


Figure 5-5 Number of Alternative Solutions to Safety Problems Generated by Technology Students in Teams: Untrained (Pretest1 and Pretest2)

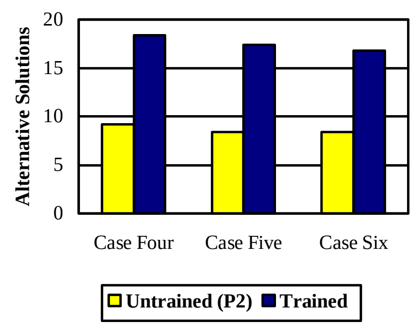


Figure 5-6 Number of Alternative Solutions to Safety Problems Generated by Technology Students in Teams: Untrained (Pretest2) and Trained

5.1.4 Industry Advisers Generating Alternative Solutions

Case	Mode	Untrained			Trained			t-test	
		N	Mean	SD	N	Mean	SD	t	p
One	Individual	24	4.9	1.7	24	6.3	2.6	t(46)=2.12	0.020
Two	Individual	24	5.3	2.6	24	7.3	2.8	t(46)=2.67	0.005
Three	Individual	24	5.6	2.0	24	7.0	2.5	t(46)=2.03	0.024
Four	Team	8	6.6	1.6	8	9.8	2.7	t(14)=2.85	0.007
Five	Team	8	9.0	2.7	8	11.3	2.5	t(14)=1.72	0.054
Six	Team	8	8.0	3.4	8	12.1	3.3	t(14)=2.48	0.013

Table 5-5 Number of Alternative Solutions to Safety Problems Generated by Industry Advisers: Untrained and Trained

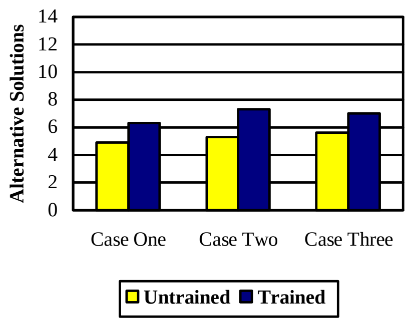


Figure 5-7 Number of Alternative Solutions to Safety Problems Generated by Industry Advisers Individually: Untrained and Trained

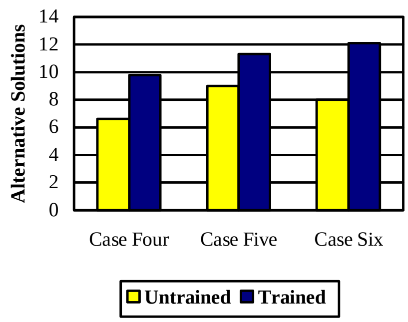


Figure 5-8 Number of Alternative Solutions to Safety Problems Generated by Industry Advisers in Teams: Untrained and Trained

5.1.5 Government Advisers Generating Alternative Solutions

Case	Mode	Condition	N	Mean	SD	t	'p'
Three	Individual	Untrained	15	6.4	1.7		
		Trained (CT)	19	7.6	2.0	t(32)=1.81	0.040a
		Trained (HM)	112	7.6	3.8	t(36)=2.06u	0.024a
		Trained (CT+HM)	33	9.3	3.5	t(143)=2.32	0.011b
Five	Team	Untrained	5	8.8	2.6		
		Trained (CT)	7	10.3	2.0	t(10)=1.13	0.142a
		Trained (HM)	31	8.7	3.4	t(34)=0.08	0.470a
		Trained (CT+HM)c	9	14.2	6.7	t(9.2)=3.40u	0.020b
		Trained (CT+HM)d	6	10.3	4.6	t(35)=1.04	0.154b
		Trained (CT+HM)e	15	12.6	6.1	t(18)=2.37u	0.015b

Table 5-6 Number of Alternative Solutions to Safety Problems Generated by Government Advisers: Untrained and Trained (Creative Thinking, Hazard Management, Combined Training)
(a) Compared to Untrained Group,
(b) Compared to Hazard Management Trained Group
(c) Whole team Creative Thinking Trained
(d) One person in team Creative Thinking Trained
(e) At least one person in team Creative Thinking Trained (1&2)
(u) Unequal-variance t-test due to significant Levene's test for Equal Variance

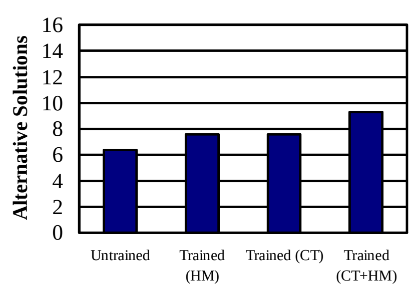


Figure 5-9 Number of Alternative Solutions to Safety Problems Generated by Government Advisers Individually: Untrained and Trained (Hazard Management, Creative Thinking & Combined Training)

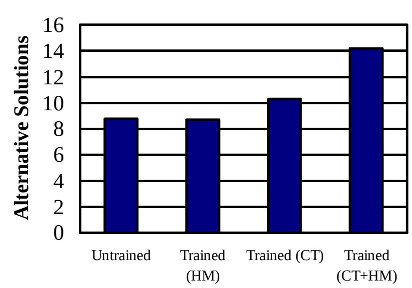


Figure 5-10 Number of Alternative Solutions to Safety Problems Generated by Government Advisers in Teams: Untrained and Trained (Hazard Management, Creative Thinking & Combined Training)

5.1.6 Generating Alternative Solutions (Number of Alternative Solutions): Summary

Table 5-7 shows the summary of the increases in the number of alternative solutions generated by subjects trained in creative thinking compared with those untrained. The summary table also notes the effect of practice for the technology students (between pretest1 and pretest2) and the effect of the hazard management training for the government advisers (who worked only on cases three and five).

Case	Mode	Tech. (a) Practice	Tech. (b) CT	Eng. CT	Ind. CT	Gov. CT	Gov. HM	Gov. (c) CT+HM
One	Individual	+38%***	+66% ***	+84% ***	+27%*			
Two	Individual	+22%*	+96% ***	+145%***	+40%**			
Three	Individual	+10%	+93% ***	+155% ***	+24%*	+18%*	+19%*	+24%*
Four	Team	+12%(d)	+100%(d)	+112%***	+47%**			
Five	Team	+11%(d)	+107%(d)	+120%***	+25%	+17%	-1%	+63%*
Six	Team	+14%(d)	+100%(d)	+153%**	+52%*			

Table 5-7 Summary of the Increase in the Number of Solutions following Creative Thinking Training

Notes:

(*/**/***) Statistically significant at 0.05/0.01/0.001 level (one tail)

(a) Technology Students *Practice* Effect is Pretest2 compared with Pretest1

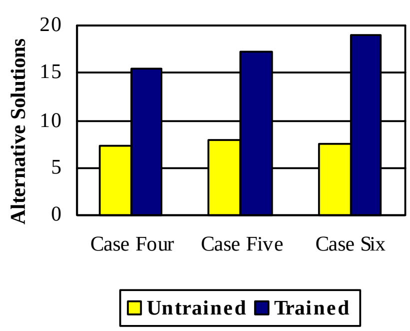
(b) Technology Students *CT* Effect is Creative Thinking Training compared with Pretest2

(c) Government Advisers *CT+HM* effect is Creative Thinking (in teams where all the Team CT Trained) + Hazard Management Training compared with those with Hazard Management Training Only

(d) Statistical test not possible

5.1.6.1 Effect of Creative Thinking Training

The figures show that creative thinking training lead to an improvement of around 100% for the



engineering (Table 5-2, Figure 5-1 & Figure 5-2) and technology students (in addition to the small gains due to practice) (Table 5-3, Figure 5-3 & Figure 5-4). No statistical test was performed on the team results from the technology students as the groups became mixed. Given the dependant nature of the data a comparison was not possible. However the changes are of the same order as the engineering students.

The industry advisers (Table 5-4, Figure 5-7 & Figure 5-8) following the creative thinking training generated about 30 to 40% more solutions that their untrained colleagues. The government advisers (Table 5-6, Figure 5-9 & Figure 5-10) seemed to exhibit a similar effect size and this effect was significant for individuals but not for teams.

Over the four groups of subjects the effect of the training was to increase the number of solutions generated by between 30% and 150%. The effect of creative thinking training was similar for teams and for individuals. These effects seemed greatest for the undergraduate students.

5.1.6.2 Effect Hazard Management Training

The hazard management training was tested only with the government advisers. Those subjects who took the training seemed to generate more solutions than their untrained colleagues when working individually but not when in teams (Figure 5-9 & Figure 5-10).

5.1.6.3 Effect of Combined Training

Those government advisers who took the hazard management training following the creative thinking training generated significantly more ideas than those who took the hazard management training only (Figure 5-9 & Figure 5-10). As mentioned above, on its own the hazard management training appeared to have little impact on the ability of the government advisers to generate solutions. The creative thinking training produced a better increase but not substantial. The substantial gains came when these two methods were combined. This outcome needs to be moderated given the effect of practice. The government advisers who took both forms of training completed the test twice and were compared with subjects who took the test only once. The results with the technology students showed a significant practice effect in generating alternatives in the order of 10 to 20%. In comparison, those government advisers who undertook the hazard management training after the creative thinking training produced solutions (24% more individually and 63% more in teams) than those who only attended the hazard management training. These results show the potential of adding *general* creative thinking training to *specific* training such as hazard management training.

5.2 Generating Effective Solutions (Proportion of Safe Place Solutions)

The effectiveness of the solutions was assessed by categorising them as either *safe-place* or *safe-person* according to a standard list of potential solutions (Appendix C). From this categorisation the number of safe place solutions can be separately analysed. The data that follows are organised according to the four subject groups. A summary of the results then follows.

5.2.1 Engineering Students Generating Effective Solutions

Case	Mode	Untrained			Trained			t-test	
		N	Mean	SD	N	Mean	SD	t	p
One	Individual	21	72	22	21	63	25	t(40)=1.23	0.113
Two	Individual	21	58	22	21	67	13	t(33)=1.61u	0.058
Three	Individual	21	53	28	20	58	20	t(39)=0.55	0.294
Four	Team	7	54	15	7	60	8	t(12)=0.91	0.190
Five	Team	7	37	10	7	49	16	t(12)=1.74	0.054
Six	Team	7	56	11	7	64	9	t(12)=1.49	0.080

Table 5-8 Proportion of Safe-Place Solutions Generated by Engineering Students: Untrained and Trained
(u) Unequal-variance t-test due to significant Levene's test for Equal Variance

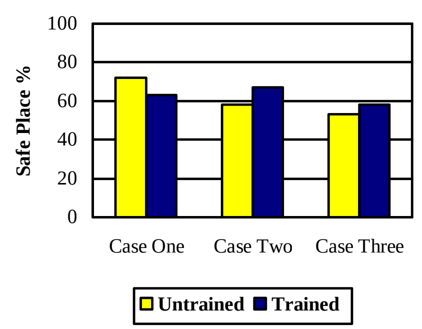


Figure 5-11 Proportion of Safe-Place Solutions Generated by Engineering Students Individually: Untrained and Trained

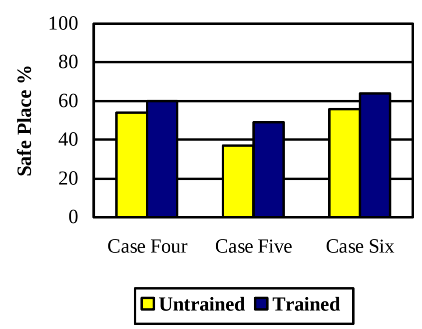


Figure 5-12 Proportion of Safe-Place Solutions Generated by Engineering Students in Teams: Untrained and Trained

5.2.2 Technology Students Generating Effective Solutions Individually

Case	Condition	N	Mean	SD	Δ	SD	t	p
One	Pretest1	18	53	23				
	Pretest2	15	41	19				
	Trained	13	60	16				
Paired t-test	Pretest1 / Pretest2	15	53 / 41	26 / 19	-12	23	-2.05	0.030
Paired t-test	Pretest2 / Trained	12	46 / 58	15 / 16	+12	20	1.99	0.036
Two	Pretest1	18	43	24				
	Pretest2	15	45	27				
	Trained	13	62	14				
	Trained (3 Months)	13	61	17				
Paired t-test	Pretest1 / Pretest2	15	41 / 45	26 / 27	+4	17	0.80	0.220
Paired t-test	Pretest2 / Trained	12	48 / 61	29 / 13	+13	30	1.48	0.084
Paired t-test	Trained / Trained (3M)	11	61 / 63	15 / 14	-2	14	-0.46	0.328
Three	Pretest1	18	34	22				
	Pretest2	15	37	23				
	Trained	13	47	19				
Paired t-test	Pretest1 / Pretest2	15	31 / 37	23 / 23	+6	15	1.44	0.087
Paired t-test	Pretest2 / Trained	12	40 / 46	25 / 19	+6	20	0.98	0.174

Table 5-9 Proportion of Safe-Place Solutions Generated by Technology Students Individually: Untrained (Pretest1 and Pretest2) and Trained

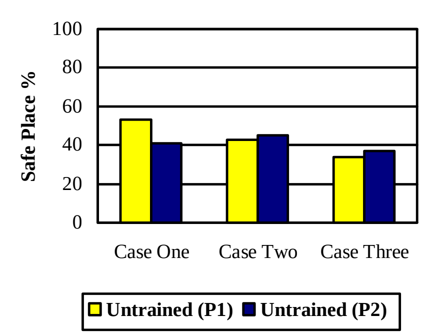


Figure 5-13 Proportion of Safe-Place Solutions Generated by Technology Students Individually: Untrained (Pretest1 and Pretest2) (Paired Data)

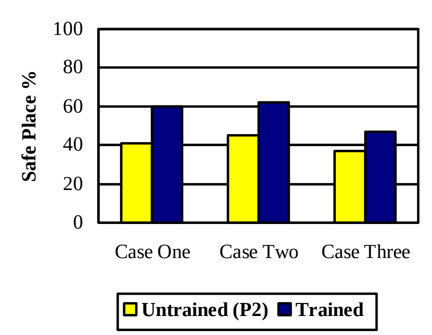


Figure 5-14 Proportion of Safe-Place Solutions Generated by Technology Students Individually: Untrained (Pretest2) and Trained (Paired Data)

5.2.3 Technology Students Generating Effective Solutions in Teams

Case	Mode	Condition	N	Mean	SD
Four	Team	Pretest1	5	36	26
		Pretest2	5	47	11
		Trained	5	59	5.7
Five	Team	Pretest1	5	29	23
		Pretest2	5	34	24
		Trained	5	47	13
Six	Team	Pretest1	5	50	17
		Pretest2	5	43	16
		Trained	5	59	3.8
		Trained (3-Month)	5	62	7.4

Table 5-10 Proportion of Safe-Place Solutions Generated by Technology Students in Teams:

Untrained (Pretest1 and Pretest2) and Trained

Note: Statistical test not possible

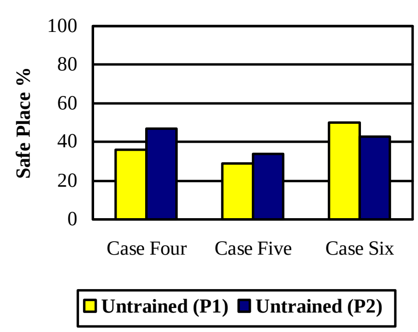


Figure 5-15 Proportion of Safe-Place Solutions Generated by Technology Students in Teams: Untrained (Pretest1 and Pretest2)

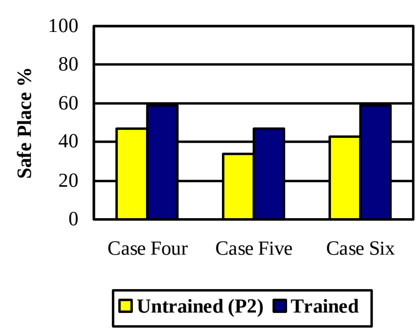


Figure 5-16 Proportion of Safe-Place Solutions Generated by Technology Students in Teams: Untrained (Pretest2) and Trained

5.2.4 Industry Advisers Generating Effective Solutions

Case	Mode	Untrained			Trained			t-test	
		N	Mean	SD	N	Mean	SD	t	p
One	Individual	24	71	24	24	70	22	t(46)=0.21	0.416
Two	Individual	24	57	19	24	69	20	t(46)=2.21	0.016
Three	Individual	24	40	22	24	55	20	t(46)=2.42	0.010
Four	Team	8	59	17	8	68	14	t(14)=1.13	0.139
Five	Team	8	44	17	8	50	19	t(14)=0.67	0.257
Six	Team	8	61	13	8	70	12	t(14)=1.43	0.088

Table 5-11 Proportion of Safe-Place Solutions Generated by Industry Advisers: Untrained and Trained

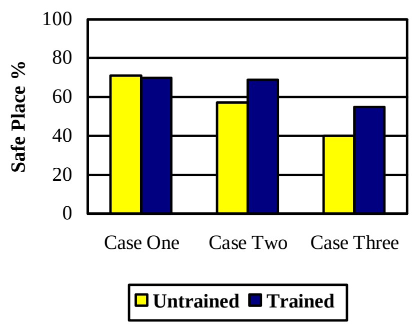


Figure 5-17 Proportion of Safe-Place Solutions Generated by Industry Advisers Individually: Untrained and Trained

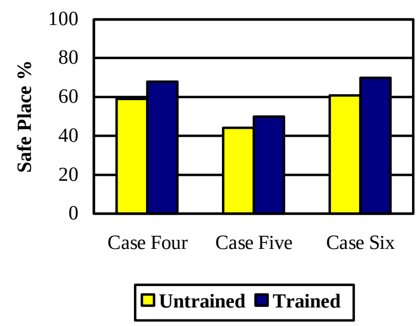


Figure 5-18 Proportion of Safe-Place Solutions Generated by Industry Advisers in Teams: Untrained and Trained

5.2.5 Government Advisers Generating Effective Solutions

Case	Mode	Condition	N	Mean	SD	t	'p'
Three	Individual	Untrained	15	42	21		
		Trained (CT)	19	45	26	t(32)=0.42	0.340a
		Trained (HM)	112	40	24	t(125)=0.20	0.421a
		Trained (CT+HM)	33	58	20	t(60)=3.91u	<0.001b
Five	Team	Untrained	5	49	18		
		Trained (CT)	7	45	19	t(10)=0.31	0.380a
		Trained (HM)	31	36	15	t(34)=1.82	0.039a
		Trained (CT+HM)c	9	53	9	t(38)=3.24	0.001b
		Trained (CT+HM)d	6	45	14	t(35)=1.39	0.086b
		Trained (CT+HM)e	15	49	11	t(44)=3.17	0.002b

Table 5-12 Proportion of Safe-Place Solutions Generated by Government Advisers: Untrained and Trained (Creative Thinking, Hazard Management & Combined Training)

(a) Compared to Untrained Group

(b) Compared to Hazard Management Trained Group

(c) Whole team Creative Thinking Trained

(d) One person in team Creative Thinking Trained

(e) At least one person in team Creative Thinking Trained (1&2)

(u) Unequal-variance t-test due to significant Levene's test for Equal Variance

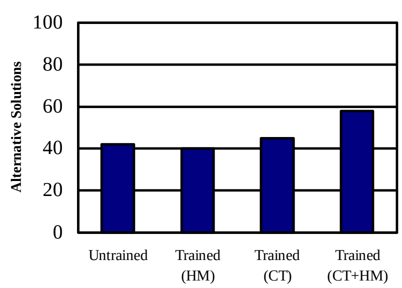


Figure 5-19 Proportion of Safe-Place Solutions Generated by Government Advisers Individually: Untrained and Trained (Hazard Management, Creative Thinking & Combined Training): Case Three

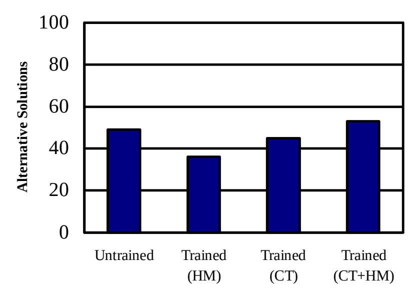


Figure 5-20 Proportion of Safe-Place Solutions Generated by Government Advisers in Teams: Untrained and Trained (Hazard Management, Creative Thinking & Combined Training): Case Five

5.2.6 Generating Effective Solutions (*Proportion* (%) of Safe-Place Solutions): Summary

As mentioned above the effectiveness of these solutions was assessed by categorising them as either *safe-place* or *safe-person* according to a standard list of potential solutions (Appendix C). The variable was the proportion (%) of safe-place solutions. The results here are grouped according to the subject groups. Table 5-13 summarises the difference in the proportion of safe-place solutions of the trained subjects compared to the untrained subjects.

Case	**Mode**	**Tech. (a)** Practice	**Tech. (b)** CT	**Eng.** CT	**Ind.** CT	**Gov.** CT	**Gov.** HM	**Gov. (c)** CT+HM
One	Individual	-23%*	+26%*	-12%	-2%			
Two	Individual	+10%	+27%	+16%	+22%*			
Three	Individual	+19%	+15%	+8%	+36%*	+8%	-3%	+45%***
Four	Team	+30%(d)	+26%(d)	+11%	+15%			
Five	Team	+18%(d)	+39%(d)	+33%	+17%	-7%	-27%*	+47%**
Six	Team	-14%(d)	+35%(d)	+14%	+14%			

Table 5-13 Summary of the Changes in Proportion of Safe-Place Solutions with Training
Notes:
(*/**/***) Statistically significant at 0.05/0.01/0.001 level (one tail)
(a) Technology Students *CT* Effect is Creative Thinking Training compared with Pretest2
(b) Technology Students Creative Thinking Training compared with Pretest2
(c) Government Advisers *CT+HM* effect is Creative Thinking (in teams where all the Team CT Trained) + Hazard Management Training compared with those with Hazard Management Training Only
(d) Statistical test not possible

5.2.6.1 Effect of Creative Thinking Training

The trained subjects appeared to generate higher quality solutions, with 17 of the cells in Table 5-13 showing an increase and only three showing a decrease, however most of the changes in the table are not significant. Some indication of possible improvement due to practice was indicated by the technology student data where there were four gains (two non-significant and two non-tested), and two decreases (one significant and one non-tested). It seems reasonable to suggest that the proportion of safe place solutions that subjects generated remained at least steady, and showed signs of an increase, following training in creative thinking.

5.2.6.2 Effect of Hazard Management Training

The hazard management training (Table 5-12, Figure 5-19 & Figure 5-20) showed little change in the quality of the ideas for individuals and a lower quality for teams.

5.2.6.3 Effect of the Combined Training

While the effects of the hazard management training alone were disappointing, the effect of the hazard management training for those who had also completed the creative thinking training were positive (Figure 5-19 & Figure 5-20). In comparison to the *hazard management training* group, the combined group generated a significantly higher proportion of safe-place solutions, both individually and in teams.

5.2.6.4 Summary Effects for Generating Effective Solutions

In summary it seems that;

- Following creative thinking training the average proportion of safe place solutions was at least maintained and there were some indications of an improvement.
- Hazard management training did not affect the proportion of safe place solutions.
- Adding creative thinking training to the hazard management training lead to an improvement in the proportion of safe place solutions

5.2.7 Generating Effective Solutions (*Number* of Safe-Place Solutions): Summary

The combination of the raw number of ideas and the average idea quality represents the *number* of good ideas. Table 5-13 summarises the difference in the number of good, safe place, solutions generated by the trained subjects compared to the untrained subjects.

Case	**Mode**	**Tech. (a)** Practice	**Tech. (b)** CT	**Eng.** CT	**IND.** CT	**GOV.** CT	**GOV.** HM	**GOV. (c)** CT+HM
One	Individual	+10%	+102%***	+71%**	+29%			
Two	Individual	+44%*	+118%***	+185%***	+73%**			
Three	Individual	+15%	+125%**	+200%***	+63%**	+22%	+17%	+65%***
Four	Team	+29%(d)	+145%(d)	+141%**	+71%**			
Five	Team	+33%(d)	+156%(d)	+200%***	+50%*	+14%	-22%	+127%***
Six	Team	0%(d)	+158%(d)	+200%**	+72%**			

Table 5-14 Summary of the Changes in Number of Safe-Place Solutions with Training
(*/**/***) Statistically significant at 0.05/0.01/0.001 level (one tail)
(a) Technology Students Practice Effect is based on Pretest2 compared with Pretest1
(b) Technology Students *CT* Effect is Creative Thinking Training compared with Pretest2
(c) Government Advisers *CT+HM* effect is Creative Thinking (in teams where all the Team CT Trained) + Hazard Management Training compared with those with Hazard Management Training Only
(d) Statistical test not possible

The results show that the training yielded large (up to 200%), statistically significant, improvements in the number of good solutions for the technology students, engineering students and the industry advisers. The training seemed to have only a modest effect with the government advisers. Similarly the hazard management training resulted in no statistically significant effect. Of note though, is the substantial, and statistically significant, differences between those government advisers who attended both forms and those who attended the hazard management training only.

5.3 Prioritizing Effective Solutions (Correlation with Optimum Rank)

One of the key variables measured was the prioritization of potential solutions. Subjects worked individually on cases seven, eight and nine and they worked in teams on cases ten, eleven and twelve. The data following is organised according to the four subject groups. A summary of the results then follows.

5.3.1 Engineering Students Prioritizing Effective Solutions

Case	**Mode**	**Untrained**			**Trained**			**Mann-Whitney Test**	
		N	Mean	SD	N	Mean	SD	U	p
Seven	Individual	21	-0.29	0.45	21	0.09	0.58	137	0.018
Eight	Individual	21	-0.08	0.50	21	0.14	0.53	162	0.068
Nine	Individual	21	0.34	0.51	21	0.61	0.41	160	0.062
Ten	Team	7	0.00	0.33	7	0.45	0.56	14.5	0.099
Eleven	Team	7	0.38	0.24	7	0.76	0.25	6.5	0.010
Twelve	Team	7	0.83	0.19	7	0.86	0.13	24.5	0.500

Table 5-15 Correlation with Optimum Ranking of a Set of Safety Solutions by Engineering Students: Untrained and Trained

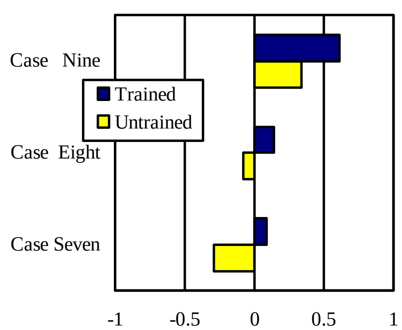


Figure 5-21 Correlation with Optimum Ranking of a Set of Safety Solutions by Engineering Students Individually: Untrained and Trained

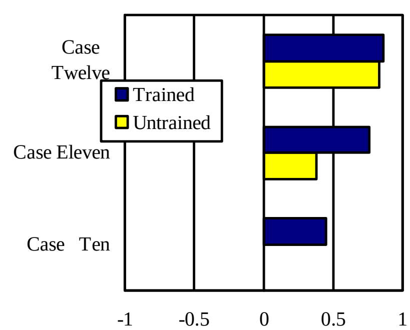


Figure 5-22 Correlation with Optimum Ranking of a Set of Safety Solutions by Engineering Students in Teams: Untrained and Trained

5.3.2 Technology Students Prioritizing Effective Solutions Individually

Case	Condition	N	r	SD	Paired Wilcoxon Test			
					Pairs	Δ	T	p
Seven	Pretest1	18	-0.33	0.54				
	Pretest2	15	-0.17	0.56	15	10+, 4-	1.16	0.122a
	Trained	13	-0.19	0.58	12	6+, 4-	0.45	0.323b
	Trained (3 Months)	13	-0.02	0.54	11	6+, 3-	1.31	0.096c
Eight	Pretest1	18	-0.40	0.55				
	Pretest2	15	-0.13	0.64	15	9+, 5-	2.04	0.021a
	Trained	13	-0.18	0.55	12	5+, 5-	0.61	0.270b
Nine	Pretest1	18	-0.05	0.56				
	Pretest2	15	0.11	0.64	15	11+, 2-	2.06	0.019a
	Trained	13	0.15	0.62	12	6+, 6-	0.00	0.500b

Table 5-16 Correlation with Optimum Rank by Technology Students Working Individually: Pretest1, Pretest2 & Creative Thinking Trained
(a) Compared to Pretest1
(b) Compared to Pestest2
(c) Compared to Trained

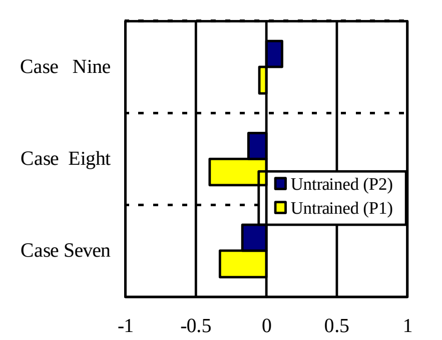


Figure 5-23 Correlation with Optimum Ranking of a Set of Safety Solutions by Technology Students Individually: Untrained (Pretest1 and Pretest2) (Paired Data)

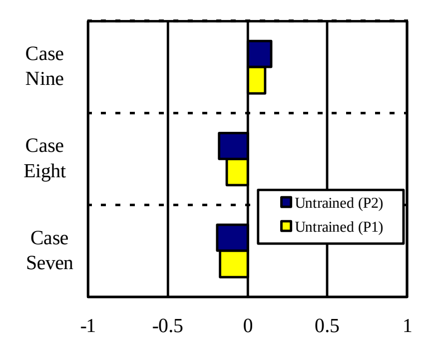


Figure 5-24 Correlation with Optimum Ranking of a Set of Safety Solutions by Technology Students Individually: Untrained (Pretest2) and Trained (Paired Data)

5.3.3 Technology Students Prioritizing Effective Solutions in Teams

Case	Mode	Group	N	r	SD
Ten	Teams	Pretest1	5	-0.08	0.49
		Pretest2	5	-0.16	0.73
		Trained	5	0.14	0.54
		Trained (3-Month)	5	0.44	0.27
Eleven	Teams	Pretest1	5	0.08	0.40
		Pretest2	5	0.13	0.25
		Trained	5	0.38	0.49
Twelve	Teams	Pretest1	5	0.26	0.70
		Pretest2	5	0.33	0.65
		Trained	5	0.29	0.87

Table 5-17 Mean Correlation with Optimum Rank by Technology Students Working in Teams: Pretest1, Pretest2 & Creative Thinking Trained
Note: Statistical test not possible as data is dependant and pairs are mixed

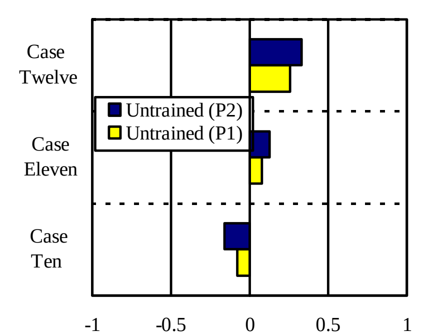


Figure 5-25 Correlation with Optimum Ranking of a Set of Safety Solutions by Technology Students in Teams: Untrained (Pretest1 and Pretest2)

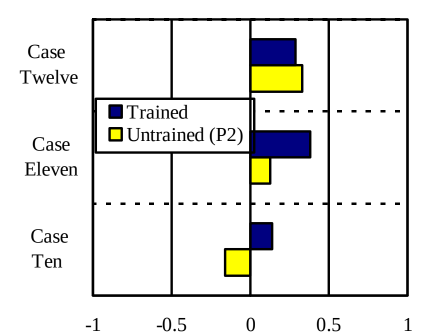


Figure 5-26 Correlation with Optimum Ranking of a Set of Safety Solutions by Technology Students in Teams: Untrained (Pretest2) and Trained

5.3.4 Industry Advisers Prioritizing Effective Solutions

Case	Mode	Untrained			Trained			Mann-Whitney Test	
		N	Mean	SD	N	Mean	SD	U	p
Seven	Individual	24	0.11	0.62	24	0.34	0.58	207	0.047
Eight	Individual	24	0.28	0.61	24	0.34	0.56	272	0.340
Nine	Individual	24	0.59	0.40	24	0.64	0.52	248	0.200
Ten	Team	8	0.84	0.31	8	0.81	0.34	24.0	0.177
Eleven	Team	8	0.84	0.16	8	0.79	0.38	28.0	0.334
Twelve	Team	8	0.84	0.18	8	0.89	0.16	25.5	0.241

Table 5-18 Mean Correlation with Optimum Rank by Industry Advisers: No Training versus Creative Thinking Trained

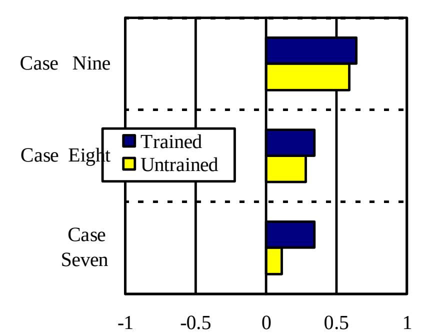


Figure 5-27 Correlation with Optimum Ranking of a Set of Safety Solutions by Industry Advisers Individually: Untrained and Trained

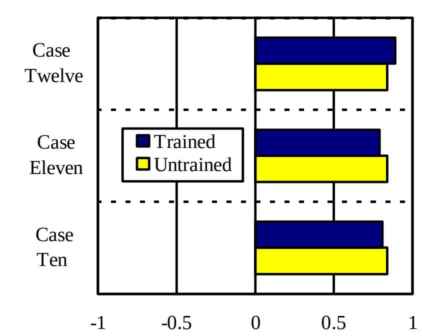


Figure 5-28 Correlation with Optimum Ranking of a Set of Safety Solutions by Industry Advisers in Teams: Untrained and Trained

5.3.5 Government Advisers Prioritizing Effective Solutions Individually

Case	Mode	Condition	N	Mean	SD	Mann-Whitney Test	
						U	p
Seven	Individual	Untrained	15	0.09	0.40		
		Trained (CT)	19	0.25	0.54	115	0.170a
		Trained (HM)	110	0.13	0.52	805	0.438a
		Trained (CT+HM)	33	0.46	0.52	1150	<0.001b
Eight	Individual	Untrained	15	0.14	0.46		
		Trained (CT)	19	0.12	0.73	137	0.424a
		Trained (HM)	111	0.30	0.59	634	0.067a
		Trained (CT+HM)	33	0.39	0.55	1670	0.227b
Nine	Individual	Untrained	15	0.29	0.62		
		Trained (CT)	19	0.10	0.68	117	0.188a
		Trained (HM)	111	0.24	0.57	765	0.304a
		Trained (CT+HM)	33	0.57	0.45	1170	<0.001b

Table 5-19 Mean Correlation with Optimum Rank by Government Advisers Working Individually: No Training, Creative Thinking Trained, Hazard Management Trained & Combined Training
(a) Compared to Untrained Group
(b) Compared to Hazard Management Trained Group

5.3.6 Government Advisers Prioritizing Effective Solutions in Teams

Case	Mode	Condition	N	Mean	SD	Mann-Whitney Test U	p
Ten	Team	Untrained	5	0.64	0.37		
		Trained (CT)	7	0.79	0.22	12.5	0.205a
		Trained (HM)	33	0.51	0.57	82.0	0.491a
		Trained (CT+HM) c	9	0.76	0.45	93.5	0.044b
		Trained (CT+HM) d	6	0.91	0.12	50.5	0.028b
		Trained (CT+HM) e	15	0.82	0.36	144	<0.001b
Eleven	Team	Untrained	5	0.54	0.40		
		Trained (CT)	7	0.63	0.23	16.5	0.435a
		Trained (HM)	33	0.53	0.44	79.5	0.449a
		Trained (CT+HM) c	9	0.81	0.28	60.5	0.003b
		Trained (CT+HM) d	6	0.68	0.33	79.5	0.223b
		Trained (CT+HM) e	15	0.76	0.30	140	0.008b
Twelve	Team	Untrained	5	0.85	0.15		
		Trained (CT)	7	0.74	0.34	16.5	0.434a
		Trained (HM)	31	0.77	0.26	76.5	0.395a
		Trained (CT+HM) c	9	0.79	0.34	128	0.253b
		Trained (CT+HM) d	6	0.83	0.21	87.0	0.316b
		Trained (CT+HM) e	15	0.81	0.29	215	0.224b

Table 5-20 Mean Correlation with Optimum Rank by Government Advisers Working in Teams: No Training , Creative Thinking Trained, Hazard Management Trained & Combined Training
(a) Compared to Untrained Group
(b) Compared to Hazard Management Trained Group
(c) Whole team Creative Thinking Trained
(d) One person in team Creative Thinking Trained
(e) At least one person in team Creative Thinking Trained (c&d)

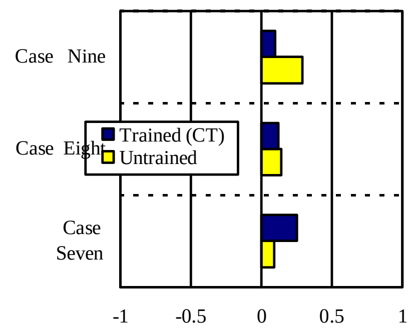


Figure 5-29 Correlation with Optimum Ranking of a Set of Safety Solutions by Government Advisers Individually: Untrained and Trained (CT)

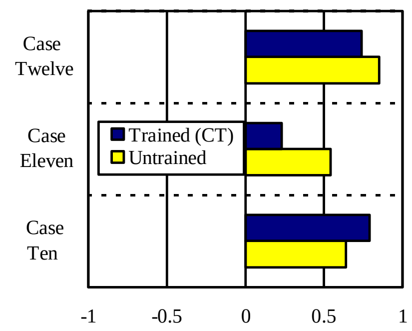


Figure 5-30 Correlation with Optimum Ranking of a Set of Safety Solutions by Government Advisers in Teams: Untrained and Trained (CT)

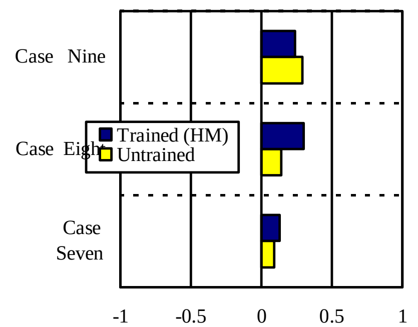


Figure 5-31 Correlation with Optimum Ranking of a Set of Safety Solutions by Government Advisers Individually: Untrained and Trained (HM)

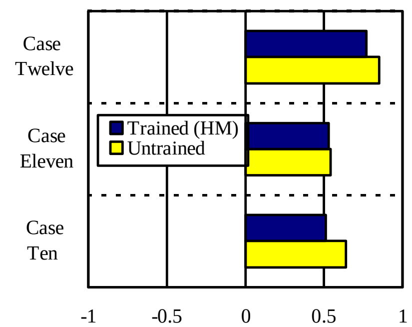


Figure 5-32 Correlation with Optimum Ranking of a Set of Safety Solutions by Government Advisers in Teams: Untrained and Trained (HM)

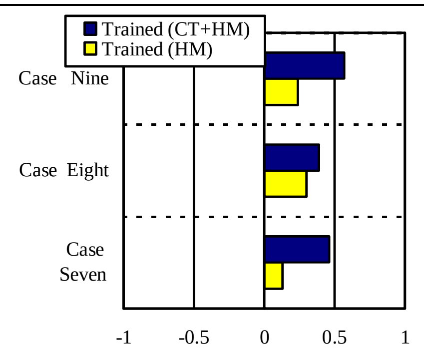


Figure 5-33 Correlation with Optimum Ranking of a Set of Safety Solutions by Government Advisers Individually: Trained (HM Only) and Trained (CT+HM)

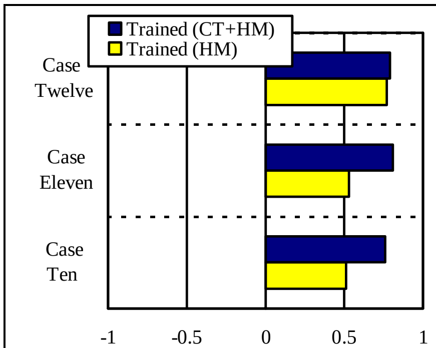


Figure 5-34 Correlation with Optimum Ranking of a Set of Safety Solutions by Government Advisers in Teams: Trained (HM Only) and Trained (CT+HM)

5.3.7 Prioritizing Effective Solutions (Correlation with Optimum Rank): Summary

Table 5-21 shows the gain or loss of trained subjects over untrained on the mean correlation of subject's ranking of safety solutions with the optimum rank.

Case	Mode	Tech. (a) Practice	Tech. (b) CT	Eng. CT	Ind. CT	Gov. CT	Gov. HM	Gov. (c) CT+HM
Seven	Individual	+0.11	-0.09	+0.38*	+0.29*	+0.17	+0.05	+0.32***
Eight	Individual	+0.31*	-0.10	+0.22	+0.06	-0.02	+0.17	+0.09
Nine	Individual	+0.18*	0.00	+0.36	+0.05	-0.19	-0.06	+0.33***
Ten	Team	-0.08(d)	+0.31(d)	+0.45	-0.03	+0.15	-0.13	+0.25*
Eleven	Team	+0.05(d)	+0.25(d)	+0.38*	-0.05	+0.09	-0.02	+0.28**
Twelve	Team	+0.07(d)	-0.03(d)	+0.03	+0.05	-0.11	-0.08	+0.02

Table 5-21 Summary of the Mean Correlation with Optimum Rank of the Trained Subjects compared to the Untrained Subjects
(*/**/***) Statistically significant at 0.05/0.01/0.001 level
(a) Technology Students Practice Effect compared with Pretest1
(b) Technology Students *CT* Effect is Creative Thinking Training compared with Pretest2
(c) Government Advisers *CT+HM* effect is Creative Thinking (in teams where all the Team CT Trained) + Hazard Management Training compared with those with Hazard Management Training Only
(d) Statistical test not possible

5.3.7.1 The Effect of Creative Thinking Training

The results tend to indicate that creative thinking training improved the prioritization of solutions by the engineers (Table 5-15, Figure 5-21, Figure 5-22). On two of the six cases (one individually and one in teams) the trained engineering students scored significantly higher than the untrained engineering students. Furthermore in case twelve both untrained and trained scored near to the maximum and so no improvement could be evident. Therefore there were significant improvements on two of a possible five cases and changes of similar magnitude on the other three cases.

The technology students (Table 5-16) demonstrated a significant improvement as individuals with practice on the test (Figure 5-23). They exhibited no practice improvement in teams (Figure 5-25), although a statistical test was not performed on the team data as the data is dependant and not able to be paired. Following creative thinking training, individuals showed no further improvement (Figure 5-24) while teams seemed to improve (Figure 5-26). Overall there seemed to be no evidence to show clearly that creative thinking training improved prioritization by the technology students.

The industry advisers (Table 5-18) and government advisers (Table 5-19 & Table 5-20) seemed to show little or no improvement as individuals following creative thinking training (Figure 5-27 & Figure 5-29). In teams also no improvement was evident but as shown by Figure 5-28 and Figure 5-30 the untrained teams of the industry advisers and government advisers performed near to the maximum. Therefore there was little room for the creative thinking trained subjects to improve, so the test is inconclusive except to note that the training showed no apparent disadvantage.

In general the creative thinking training had a positive effect on the way that engineering students prioritized solutions but this effect was not evident for other groups.

5.3.7.2 The Effect of Hazard Management and Combined Training

The hazard management training produced no effect on the ability of government advisers to prioritize solutions (Figure 5-31 & Figure 5-32). However those who completed the creative thinking training prior to the hazard management training showed improvement on this task when compared with those who undertook hazard management training only (Figure 5-33 & Figure 5-34). This is moderated by the effect of practice demonstrated with the technology students (Figure 5-23 & Figure 5-25). The combined training group had completed the test once before and so some improvement due to practice might be expected. The effects appear larger than the practice effects noted with the technology students however the results remain somewhat uncertain.

5.4 Novice/Expert Effects

The study involved groups of widely varying expertise. The following are comparisons of the four groups of subjects on the three variables (generating alternative solutions, generating effective solutions, and prioritizing effective solutions).

5.4.1 Novice/Expert Effects: Generating Alternative Solutions

Case	**Mode**	**Mean Number of Solutions Untrained**				**ANOVA**	
		Tech	**Eng.**	**Ind.**	**Gov. (a)**	F	p
One	Individual	4.9	4.9	4.9		F(2, 62)=0.001	0.999
Two	Individual	4.8	4.9	5.3		F(2, 62)=0.246	0.783
Three	Individual	5.1	4.4	5.6	6.4	F(3, 77)=3.553	0.018
Four	Team	8.2	7.3	6.6		F(2, 19)=0.738	0.493
Five	Team	7.6	7.9	9.0	8.8	F(3, 24)=0.352	0.788
Six	Team	7.4	7.6	8.0		F(2, 19)=0.059	0.943

Table 5-22 Number of Alternative Solutions by Untrained Engineering Students, Technology Students, Industry Advisers, and Government Advisers: Comparison by Analysis of Variance

(a) Government Advisers completed cases three and five only

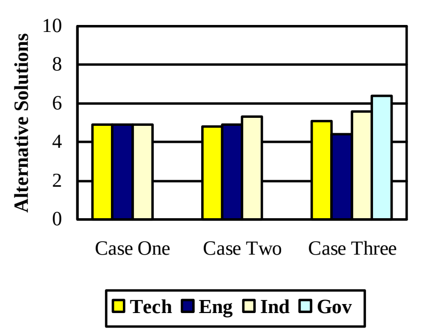


Figure 5-35 Number of Alternative Solutions by Untrained Engineering Students, Technology Students, Industry Advisers, and Government Advisers Individually

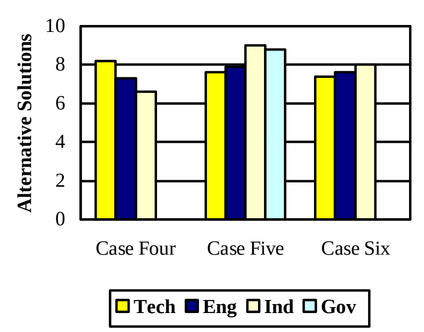


Figure 5-36 Number of Alternative Solutions by Untrained Engineering Students, Technology Students, Industry Advisers, and Government Advisers in Teams

5.4.2 Novice/Expert Effects: Generating Effective Solutions

Case	Mode	% Safe-Place Solutions Untrained				ANOVA	
		Tech	Eng.	Ind.	Gov. (a)	F	p
One	Individual	53	72	71		F(2, 62)=4.355	0.017
Two	Individual	43	58	57		F(2, 62)=2.810	0.068
Three	Individual	34	53	40	42	F(3, 77)=2.332	0.081
Four	Team	36	54	59		F(2, 19)=2.251	0.136
Five	Team	29	37	44	49	F(3, 24)=1.416	0.269
Six	Team	50	56	61		F(2, 19)=0.976	0.397

Table 5-23 Proportion of Safe-Place Solutions by Untrained Engineering Students, Technology Students, Industry Advisers, and Government Advisers: Comparison by Analysis of Variance

(a) Government Advisers completed cases three and five Only

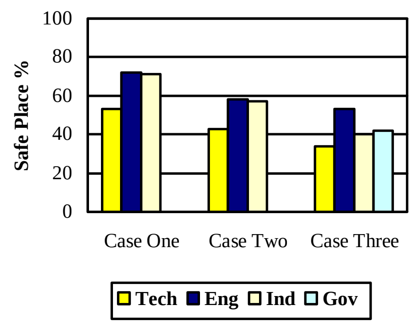


Figure 5-37 Proportion of Safe-Place Solutions by Untrained Engineering Students, Technology Students, Industry Advisers, and Government Advisers Individually

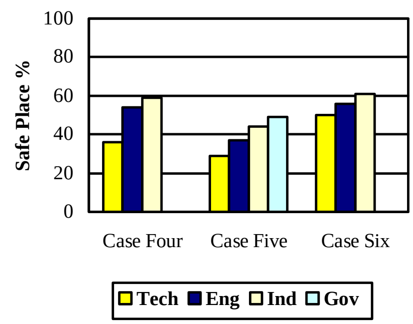


Figure 5-38 Proportion of Safe-Place Solutions by Untrained Engineering Students, Technology Students, Industry Advisers, and Government Advisers in Teams

5.4.3 Novice/Expert Effects: Prioritizing Effective Solutions

Case	Mode	Correlation with Optimum Rank Untrained				Kruskal-Wallis ANOVA	
		Tech	Eng.	Ind.	Gov. (a)	KW	p
Seven	Individual	-0.33	-0.288	0.109	0.087	KW(3)=12.74	0.005
Eight	Individual	-0.40	-0.081	0.279	0.135	KW(3)=15.38	0.002
Nine	Individual	-0.05	0.342	0.590	0.292	KW(3)=13.32	0.004
Ten	Team	-0.084	-0.004	0.835	0.636	KW(3)=16.53	<0.001
Eleven	Team	-0.076	0.379	0.841	0.544	KW(3)=13.65	0.003
Twelve	Team	0.256	0.830	0.836	0.850	KW(3)=4.787	0.188

Table 5-24 Correlation with Optimum Ranking of a Set of Safety Solutions by Untrained Engineering Students, Technology Students, Industry Advisers, and Government Advisers: Comparison by Analysis of Variance

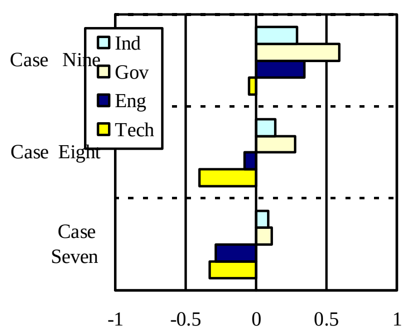


Figure 5-39 Correlation with Optimum Ranking of a Set of Safety Solutions by Untrained Engineering Students, Technology Students, Industry Advisers, and Government Advisers Individually

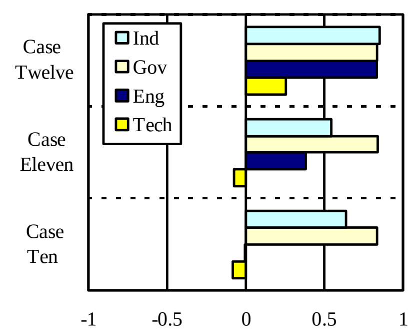


Figure 5-40 Correlation with Optimum Ranking of a Set of Safety Solutions by Untrained Engineering Students, Technology Students, Industry Advisers, and Government Advisers in Teams

5.4.4 Novice/Expert Effects: Summary

5.4.4.1 Generating Alternative Solutions

The comparisons (Table 5-22) show that there were no apparent differences along the novice to expert continuum in terms of the number of solutions produced to a given problem (Figure 5-35 & Figure 5-36). There was no evidence to suggest that those experienced in handling safety problems (industry and government advisers) were any more able to generate alternative solutions than those with no experience (engineering and technology students). This seemed equally true for individuals and for teams.

5.4.4.2 Generating Effective Solutions

Table 5-23 shows that when in working in teams there was no difference between novices and experts in the proportion of safe-place solutions (solution quality) that they generated (Figure 5-38). On one case out of three (case one) shows that there appeared to be differences between the groups when working as individuals. Figure 5-37 shows that the difference one this one case seemed to be due to the poorer performance of the technology students; the other groups are closely grouped.

5.4.4.3 Prioritizing Effective Solutions

The task of prioritizing solutions showed the value of expert opinion. For every case, whether working as individuals or as teams, the results showed that the four groups (technology and engineering students, and industry and government advisers) were significantly different (Table 5-24). A visual examination (Figure 5-39 and Figure 5-40) shows that the groups are separated in the following order, from the most well-aligned to the optimum (industry advisers) to the least well-aligned (first-year technology students).

1. Industry Advisers
2. Government Advisers
3. Engineering Students
4. Technology Students

5.5 Results Summary

The main intervention in this research was a training program in creative thinking. A second intervention was a training program in hazard management. The subjects for the research were undergraduate engineering and technology students, industry-based safety advisers and government-based safety advisers. The dependent variables were based on responses to safety case studies. Subjects were required to generate solutions to problems and to prioritize given solutions to other problems. Two variables were drawn from the first task; the number of alternative solutions; and the potential effectiveness of those solutions (proportion safe place solutions). The third variable was the correlation of each subject's prioritization of potential solutions with an optimum ranking of those solutions.

The results show that the creative thinking training lead to large increases in the number of solutions generated by the undergraduate students and moderate increases by the industry and government advisers. The quality of those solutions, being the proportion of safe place solutions tended to either increase (about half the cases in total) or remain unchanged. The net result was substantial increases in the output of potentially good solutions.

The creative thinking training did not seem to have a substantial impact on the ability to prioritize solutions. In the case of the engineering students an improvement was noted but this was not evident with any other subjects.

The hazard management training (government advisers only) did not lead to any increase in the generation of solutions either in terms of number of solutions or the proportion of safe place solutions among those alternatives.

In comparing novices and experts, there seemed to be no difference in the generation of alternative solutions in terms of the number of solutions and some minor effects on the quality of those solutions (the most novice subjects lower on one case as individuals). The prioritization of solutions, however showed substantial differences between experts and novices. Experts clearly tended to favour the safe place solutions.

Chapter Six

Discussion

6. <u>Discussion</u>

The key variables measured were;

1. The generation of alternative safety solutions.
2. The generation of effective safety solutions.
3. The prioritization of safety solutions.

6.1 Generating Solutions to Safety Problems

The issues surrounding the first two variables, the number and potential effectiveness solutions generated, are discussed together, under this heading of *Generation of Solutions to Safety Problems.*

6.1.1 Creative Thinking Training and the Generation of Solutions

Training in creative thinking for subjects with a variety of health and safety expertise lead to large improvements in the generation of safety solutions. This effect was shown with each group of subjects who took part in the research. The effect of the training in creative thinking was of the order of 100% with the undergraduate students and a little more modest with the other subjects (around 30 to 40%). The improvements found when subjects worked individually and when they worked in teams of three were of similar magnitude.

The effects found here are similar to those found in studies of the brainstorming methods. While most research on brainstorming has studied *components* of brainstorming, such as the impact of teamwork, or the effect of criticism, some studies have shown the positive effect of actual *training* in brainstorming on the ability to generate ideas (Meadow & Parnes 1959; Parnes & Meadow 1959; Parnes 1961; Reese and Parnes 1970; Baer 1988). The effect sizes, where reported, were similar to the findings found in this research; for instance Parnes and Meadow (1959) reported a 100% improvement. Sometimes studies of brainstorming have not included any training but instead have examined the effect of encouraging subjects to make use of the brainstorming *instructions* as they work on the problems. Like the studies of training in the brainstorming methods, these studies have shown that using the brainstorming *instructions* leads to increased idea output (Parnes & Meadow 1959; Meadow, Parnes & Reese 1959; Weisskopf-Joelson & Eliseo 1961; Parloff & Hanson 1964; Sappington & Farrar 1982; Szymanski & Harkins 1992). The size of the effect, has been between 70% and 450% increase in total ideas (Parnes and Meadow 1959; Weisskopf-Joelson & Eliseo 1961; Parloff and Hanson 1964; Szymanski & Harkins 1992) and between 50% and 100% increase in good ideas (Meadow, Parnes & Reese 1959; Parloff and Hanson 1964; Sappington and Farrar 1982).

While a few studies have failed to find an effect for brainstorming training (Cohen, Whitmyre & Funk 1960; Kabanoff & Bottger 1991) the consensus seems to be that emphasising the brainstorming instructions can be effective and training in the brainstorming techniques is also effective. The results here show a similar effect for training in creative thinking training that was based on de Bono's six hats method. The results here demonstrated an effect for training in creative thinking of between 20% and 150% increase in total ideas and 20% to 200% increase in good (safe place) ideas.

6.1.2 Mechanisms that Facilitated the Generation of Solutions

The training emphasised focussed thinking. During the training subjects were required to direct their attention toward a particular type of thinking. For instance when creative thinking was called for, trainees were encouraged to do *green hat* thinking for a short period of time. During green hat thinking, other types of thinking were excluded. The same was true for using any hat; other types of thinking should be excluded. The intense focus on one type of thinking contrasts with every-day thinking that is often not directed toward any particular objective.

In the same vein as encouraging more focussed thinking, the training emphasised that the subjects should take specific control over their own thinking and *choose* what type of thinking was appropriate at a certain time. They were encouraged to make an effort to take a *helicopter* view of problems rather than take a narrow reactive approach. This was best emphasised by the use of the *blue hat* in allocating time to the planning of the kind of thinking needed, rather than actually thinking about the situation itself. One would imagine that encouraging helicopter thinking would be worthwhile in improving the outcomes of creative thinking as it encourages a broad view and an openness to the possibility of multiple solutions, and from this a less immediate evaluation of ideas.

For good application of the six thinking hats, there needs to be an appreciation of the overall thinking process. For instance, being able to focus on one type of thinking to the exclusion of another, is predicated on knowing how that piece of focussed thinking fits into a larger process. The over-viewing of thinking could be described as metacognition. Metacognition has been defined as; '*knowledge concerning one's own cognitive processes and products ... (and) the active monitoring and consequential regulation of these processes in relation to the cognitive objects or data on which they bear*' (Flavell 1976 in Biggs 1987, p. 10), or '*thinking about one's own thinking*' (Smith 1992, p. 25). Sternberg (1990a) and Arlin (1990) drew parallels between wisdom and metacognition. The encouragement of a metacognitive approach should assist the application of creative thinking by generating an appreciation of its place in a wider context.

The training involved short periods of intense thinking. This may have created a belief among the subjects that they are capable of productive thinking in a short time. If subjects gained an enhanced expectation of their own ability then this may have translated into improved performance. While there is little research directly into the effect of *perception of ability* on idea production, a few research studies have assessed the effect of setting goals, which may be related. For instance Latham and Saari (1979) and Locke (1982) found that goal setting had a positive effect. However later, after improving on some methodology problems in Locke's study, Lorenzi (1988) failed to show that goal-setting made any difference. The effect of goal-setting would not necessarily be the same though as the effect of a higher perception of ability. Therefore, it still seems reasonable that enhancing subjects perception of their own ability potentially had a positive effect on performance.

Osborn (1953) described criticism as cold water on ideas while cooperation and improvement of other people's ideas were the hallmarks of successful creative teamwork. Within the training there was discussion and exercises that emphasised how the dominance of criticism in our thinking and the seemingly natural tendency toward argument in our culture form blockages to creative thinking. Some research has shown that being critical offers a prestige advantage (Amabile 1983). Amabile showed that those who are critical are perceived as more intelligent by peers than those who are more supportive. Given this finding there is a good reason for people to be critical; they appear smarter. However the presence of criticism is not seen as a useful feature of creative efforts. The early self-evaluation of ideas (Sappington & Farrar 1982) and the injection of external criticism (Smith 1993) have been shown by research studies to impede creative performance. Even *apprehension* about the prospect of being evaluated by others has been shown to reduce the output of idea generation (Diehl & Stroebe 1987). Once convinced of the negative effect of criticism on creative performance, subjects may have been motivated to take some action to minimise criticism. Obviously this has particular application to team thinking, but it is also plausible that individual thinking could have been aided by addressing a typical critical approach.

The accomplishment of a less critical approach may have been enhanced by the six hats model. The training encouraged a separation of thinking tasks into bite-size activities. This model has the potential to give freedom for those who feel the need to be critical, but who know of its deleterious effect on creative performance, to be helpful and creative when generating ideas, with the knowledge that criticism will be allowed at a certain time. The points above about the focus created by the six hats model are relevant here. While an explanation and demonstration of the negative influence of criticism may have encouraged a change of approach, this would have be enhanced by the use of the six hats tool that provided a simple method to allocate *thinking time* to creative thinking.

Some research has shown that the difference in the performance of brainstorming groups and non-brainstorming groups was due to the large amount of ideas that the group actually enunciated but failed to recognise as worthwhile ideas (Parloff & Hanson 1964). It would seem then that encouraging participants to recognise the value in ideas would be worthwhile in improving creative performance. Judgement of the ideas should be delayed and in addition some specific effort should be made to find value in the ideas and develop them into something useful. Often during the training it was emphasised and demonstrated that some value can often be found in ideas that initially appeared useless. This demonstration may have created an openness to the exploration of possibilities and a reduction of critical thinking.

As mentioned above, the minimisation of criticism and the enhancement of cooperation is seen as essential to teamwork. In groups the six hats model provides a structure to facilitate a cooperative approach to thinking. The emphasis in the training was on each person in a group thinking with the same hat. For instance, if a group was working on *green hat*, then the whole group were working on green hat. The method has the capacity to free those who perhaps feel as though they need to provide a balancing or cautioning role, to be able to go along with idea generation, knowing that a time would come when all would make an effort in the cautious role. An effort to balance ideas seems to be a normal feature of everyday conversations. The six hats method provided a simple structure to allow all people to avoid this tendency and work on one line of thinking at a time. This seems like a more productive strategy than the *balancing* of ideas that seems normal.

Finally, the training emphasised that it is possible to use techniques to generate ideas. Participants learnt and practiced using techniques to enhance active divergent thinking and thus improve the generation of alternative solutions. While this processes is linked to other elements such as the reduction of criticism, cooperation, and an openness to ideas, it is not just these factors. Participants hopefully completed the training with some understanding of how to employ simple techniques of divergent thinking to get ideas moving quickly. There is little background research about the effectiveness of such methods. Bouchard (1972) compared brainstorming groups using the analogy technique with those not using the technique. The results however were not clear, in one instance those using analogy generated 100% more ideas, however this did not occur for all problems in the research. While research in this area is minimal, the techniques of active divergent thinking are widely cited as important features in creative thinking and so one would expect that developing a skill in the methods could lead to improved performance.

In summary the mechanisms within the training in the research here that would seem to have facilitated improvement in creative output are;

- encouraging more focussed thinking
- encouraging metacognitive control, or helicopter vision
- creating a belief in the ability to perform at a high level

- encouraging the minimisation of criticism
- providing a structure for thinking that facilitates a reduction in criticism
- encouraging an openness to the possibility of alternatives and the value in other ideas
- encouraging and providing a structure for cooperation in teams
- developing a skill in the techniques of active divergent thinking.

6.1.3 Group versus Individual Effects

The level of research that has focussed on the brainstorming model or its components is indicative of the influence of brainstorming on the understanding of creative processes. While Osborn (1948) wrote about techniques of active divergent thinking, the model that seemed to catch attention was group brainstorming and the few simple rules that it involved. Osborn cautioned that group work was not always likely to be an effective way to generate ideas. These words have been vindicated many times since, and a few times prior to Osborn, in studies that examined the performance of groups compared with the performance of individuals. Typically these research programs have compared an interacting group with a nominal group. A nominal group was usually taken to mean the combination of the efforts of a number of individuals who worked alone. These studies have found that nominal groups, that is individuals, are capable of greater idea output alone than if they worked together in a group. This finding has been mainly shown for groups of four (for example; Taylor, Berry & Block 1958; Bouchard, Barsaloux & Drauden 1974; Harari & Graham 1975; Graham 1977; Maginn & Harris 1980; Jablin 1981; Diehl & Stroebe 1987; Diehl & Stroebe 1991; Thornburg 1991; Stroebe, Diehl & Abakoumkin 1992; Camacho & Paulus 1995; Furnham & Yazdanpanahi 1995; Paulus, Larey & Ortega 1995) but also for larger groups (Bouchard & Hare 1970; Bouchard, Barsaloux & Drauden 1974).

Given the failure of groups to perform to expectations one might wonder why they were included in this study. Some of the research studies showing the negative influence of interacting groups also surveyed the participants and found that while the interacting groups were less effective, the participants perceived the opposite. People involved in groups perceived them to be more effective than individual work. Furthermore there are strong organisational trends toward the use of teams. It seems that team thinking is a part of organisational life and so it was clear that the research here must be done with the improvement of team performance in mind as well as the improvement of individual performance. The research here did not aim to repeat the examinations of the *relative* performance of individuals and teams, but rather to test the effect of training in both ways of working because they are both important in an organisational context.

Virtually all the results found here were of similar *magnitude* for individuals and teams. Given the similarity of the effects for individual and team work the results are not discussed in the these terms any further. Whether problems are solved in teams or individually, the output of either way of working can be enhanced by about the same amount via the use of creative thinking skills.

6.1.4 The Effectiveness of the Solutions

The most immediately apparent question following a claim about the production of more alternatives to a problem concerns the potential usefulness of those ideas. An evaluation of the quality of solutions along with the quantity of the solutions has thus been a common model in many studies of creative thinking following the well-accepted model put forward by Guilford (1950). The research here did not differ and made an evaluation of the quality of solutions in terms of their potential effectiveness by determining the proportion of safe place solutions among the list of alternatives.

The total output of ideas by either novices or experts was improved following training in creative thinking. With this improvement there seemed to be no change in the proportion of safe place solutions (although not significant changes there were many more instances of improvements that reductions).

Given the proportion of safe place ideas was maintained the increase in total ideas was accompanied by large increases in the number of safe place solutions. The success of problem solving is predicated by the ability to generate potential courses of action. The ability to recognise good solutions from poor is important, however this ability is of no value if there is nothing from which to choose. The research here showed that creative thinking training was an effective way to enhance the generation of solutions for safety problems. The increases in safe place solutions of up to 200% generated by the engineers following training was especially encouraging.

6.1.5 Transfer of Creative Thinking Skills

Most of the evaluations in studies of brainstorming have required participants to work on similar problems as they encountered within the training. Often these problems were novel problems of the type used as examples within the training (Parnes & Meadow 1959; Parnes 1961; Reese and Parnes 1970; Baer 1988). There are some studies that avoided the type of problems in the subsequent testing (Meadow & Parnes 1959), however they are in the minority as there seems to be little report of studies that emphasise the use of evaluation problems that are of a type *distinct* from those already used in the training. The research here thus represents a variation from many studies. The tests here used a specific type of problem; safety problems. This topic was deliberately avoided during the training. The creative thinking training included no information about accident prevention; no safety examples of any kind were used in the training. The enhanced performance on problems outside the sphere of the examples emphasised during the training shows a skill transfer from the training to other problem types. Guilford (1987) commented that transfer of skills to real problem situations may be problematic unless specific analogies or demonstrations are used that show participants the link. In this study no effort was made to show a link between the training and the safety problems and so the size of the effect that was measured is even more significant. Clearly subjects have transferred the skills in the training and applied these to the safety problems in the test.

6.1.6 Creative Thinking Training as a 'Priming' Exercise

The government advisers who took the hazard management training without any prior training in creative thinking made little progress as a result of the hazard management training. As stand-alone program, the training in hazard management seemed to have only a small impact on the ability to generate alternative solutions to safety problems. In contrast, following the hazard management training, subjects who previously trained in creative thinking, generated many more ideas (especially in teams) than those subjects who had only completed the hazard management training. The confounding factor was that the subjects completing both forms of training had taken the test twice and were thus compared to subjects who had completed the test only once. Possibly those completing the test the second time may have improved with practice alone. Past research in creative thinking has shown that there can be an improvement on a test like this with practice alone (Kabanoff and Bottger 1991; 30% improvement), however it's been more common to find that no improvement resulted from practice alone (Campbell 1968; de Sánchez, Astorga, de Blanco & de Griffin 1983 in Nickerson, Perkins & Smith 1985; Baer 1988; Goff 1992).

The study with the technology students showed that the improvement on the test with practice alone was about 25% for individuals and about 10% when working in teams. In comparison, the improvement in the effectiveness of hazard management training by the addition of creative thinking training as a priming exercise was about 25% for individuals and about 60% in teams. The size of practice effect noted with the technology students is therefore about equal to the improvement noted for individuals but substantially less that that noted for teams. Therefore, for teams at least, it seems that the improvement noted for the government advisers after they completed the hazard management training, *and* having first completed the creative thinking training, was probably due to this combination of training and not practice. Furthermore the effect size of about 60% is reasonably large. Interestingly, when only one of the team of three had been to the creative thinking training, the teams generated 20% more than those where there were no creative thinking trained members, however this effect was not significant and also should be considered in light of the possible impact of a practice effect.

As single interventions the creative thinking and hazard management training had little impact on the generation of solutions among the government advisers. However, it seems that the training in creative thinking was a useful *primer* for the hazard management training. Furthermore, the effectiveness of the hazard management training in terms of the ideas generated following training was greatest among those participants who had been pre-trained in creative thinking.

6.1.7 Generalising the Effects to other Creative Thinking Techniques

As discussed earlier, the following features of the training modelled on the six thinking hats technique would seem likely to have influenced the enhanced production of ideas: focussed thinking; helicopter vision; belief in ability; minimisation of criticism; openness to ideas; encouraging cooperation; and the techniques of active divergent thinking. The presence of these factors would seem to represent the basis of a good model for creative thinking. They build on the psychological theory that the mind is most adept at the repetition of ideas and this function forms something of a barrier to the generation of new ideas; a theory widely discussed from early this century (example; Spearman 1930; Köhler 1930). Also the range of factors present in the six thinking hats model would seem to be common to techniques promoted by many writers on creative thinking (for example Osborn 1948; Gordon 1961; Adams 1987; Rickards 1988; Dacey 1989; Barry & Rudinow 1989). Given that the six thinking hats seems to share this relationship with creative thinking in general, one might expect that other models embodying these principles would yield a similar result.

6.1.8 Novices and Experts Generating Solutions

Among the research subjects were groups of varying health and safety expertise. For instance the technology students had no specialist safety education or experience, and while aligned toward a technical career by their choice of course, their knowledge about safety should be akin to that of the general community. Therefore the technology students could be described as novices in the area of safety. The other extreme was the industry adviser group who would be among the most safety knowledgable people in the community; they were involved in a post-graduate course in safety and most worked in specialist safety roles. The industry advisers could be referred to as experts. Between these two extremes were the engineering students who had the benefit of undergraduate safety education and the government safety advisers, who had extensive experience in the field, and some exposure to education via short training courses.

It would seem logical to assume that health and safety expertise gained through study and experience (*expert level*) would be useful when proposing alternative solutions to a safety problem. However this contention was not supported by the results. When generating solutions to safety problems, the technology students, engineering students, government advisers, and industry advisers all performed at the same level.

One might expect that the quality of the solutions produced by novices would be lower. On this topic, Perkins (1981), writing on creative thinking in general, argued that in terms of the effectiveness of solutions, information and knowledge are an important *precursor* to creative tasks to direct efforts in an ultimately useful way. In this area, Stavy, Meidav, Asa and Kirsch (1991) found that physics experts took conceptually difficult but expedient abstract approaches to solving physics problems while students preferred conceptually easier but more laborious approaches. Similarly, Tudor (1992) found that experts in environmental management were superior to novices in developing solutions both in terms of number and potential effectiveness, and Grosswald (1992) showed that experienced medical practitioners considered more possibilities in medical problem solving than undergraduate medical students. This line of thinking would suggest that experts in safety would generate a greater proportion of good ideas; that their idea-producing efforts would be focussed in a more efficient manner.

The research here found little support for a hypothesis that experts would generate a greater proportion of safe place solutions. The only indication that specialist knowledge may lead to a greater production of *good* ideas was the relatively poorer proportion of safe place solutions generated by the technology students (*safety novices*) on one case (out of three) when working individually. However, in contrast the engineering students performed at a similar level to the subjects with more expertise. Furthermore when subjects worked in teams the effect was not apparent at all; that is, even the technology students performed at a similar level. In addition, the proportion of safe place solutions by the technology students increased nearer to the level of the other groups following their training in creative thinking.

Similarly, if knowledge about prevention was relevant to the generation of a greater proportion of safe place solutions then one would imagine that training in hazard management would enhance this ability. However the hazard management training with the government advisers did not improve the proportion of safe place solutions. The training lead to no detectable change in the performance of individuals and a significant *drop* in the performance of teams. Untrained teams generated about 50% safe place solutions while those teams working with the benefit of the hazard management training generated about 35% safe place solutions. This result was peculiar as one would expect that the training would focus attention on safe place solutions, and the results on the prioritization task did not indicate any tendency away from the safe place paradigm after the hazard management training. For the generation of solutions, it must be noted that all other subjects completed three case studies individually and three in teams, whereas the government advisers completed only one case study individually and one in teams. Thus, attempting to explain the apparently negative effect may be futile. While statistically significant it would seem to be unwise to make strong claims based on this result, given its counter-intuitive nature, and that the hazard management training was only tested on only one group and the testing was only one third as extensive.

Taking all the outcomes into account it seems that the level of safety expertise has little bearing on either the number of solutions or the proportion of safe place solutions.

6.1.9 The Relative Success of Novices

6.1.9.1 The Irrelevance of Specialist Information in Idea Generation

The level of safety expertise did not seem to have any bearing on the ability to generate alternative solutions to safety problems. Historically, in the study of problem-solving methodology, information has been seen as the vital beginning point (for example; Ribot 1906; Wallas 1926; Harrisberger 1966; Gordon 1969; Bransford & Stein 1984; Zechmeister & Johnson 1992). From the base of information the remainder of the process was thought to follow (first gather information, then incubate, and so on). While this model remains popular, many authors on creative thinking have moved away from relying on the mere presence of sufficient information to provide the creative jolt. For some time these authors have stressed the importance of divergent thinking techniques to provoke the mind toward new ideas (for example; Osborn 1948; Gordon 1961; Allen 1962; Koestler 1969; de Bono 1971; Koberg 1981; Adams 1986; Rickards 1988; Barry and Rudinow 1989). These writers have generally suggested that, while information is a component of successful problem solving, it's presence alone will often fail to produce high creativity. They've stressed that the generation of ideas is more dependent on skills of active divergent thinking. Thus it is arguable that the lack of difference between novices and experts on the generation of solutions to safety problems is no surprise.

6.1.9.2 Knowledge and its Role in Encouraging Evaluation

Since Osborn (1948) popularised the brainstorming model, many research studies have showed the value of employing the *non-evaluative* brainstorming instructions when generating ideas (Meadow & Parnes 1959; Parnes 1959; Parnes & Meadow 1959; Meadow, Parnes & Reese 1959; Parnes 1961; Weisskopf-Joelson & Eliseo 1961; Parloff & Hanson 1964; Reese and Parnes 1970; Sappington & Farrar 1982; Baer 1988; Szymanski & Harkins 1992). Removing evaluation from the idea generating phase of problem solving is a key part of strategies designed to facilitate the generation of ideas.

One would assume that those *most able* to evaluate ideas would be those with specialist knowledge. For instance, in this research, the experts were shown to better discriminate good ideas from poor ideas. In contrast, novices do not have the knowledge to properly evaluate the ideas and thus performed poorly when called upon to prioritize solutions. Possibly the presence of sufficient knowledge to make evaluations, encourages the making of evaluations. If so, then the presence of knowledge would impede the generation of ideas. However, if this argument is sound, then it suggests that novices would be *more* productive than experts. Unfortunately this effect was not observed; there seemed to be *no difference* between novices and experts. This conundrum aside, the link between the presence of knowledge and the ability to evaluate that naturally follows, combined with the established relationship between evaluation and poor performance, may go some way toward explaining the poorer than intuitively expected performance of the experts on the task of generating solutions.

6.1.9.3 Problem Relevance and Dominant Paradigms

There have been a few studies of training in brainstorming that tested idea-output in relation to the type of problem. These studies examined problem types such as *relevant* versus *irrelevant* problems, and *real* versus *unreal* problems (Parloff & Hanson 1964; Harari & Graham 1975; Diehl & Stroebe 1987). The main idea of these studies seemed to be to examine the change in performance between working on problems *close* to one's own experience and working on problems *removed* from one's own experience. While Parloff & Hanson (1964) failed to show an effect for varying the problem type in this way, later studies showed that idea output was depressed by problems that were highly *relevant* to the subjects (Harari & Graham 1975) or highly *controversial* to the subjects (Diehl & Stroebe 1987). Some studies have examined the link between the potential end uses of the ideas and the productive output. Sessions that seemed to lead to direct consequences lead to less ideas that when the session seemed to be a training exercise only (Maginn & Harris 1980). Generally there seems to be some evidence that problems that are *relevant, real,* or maybe, *serious*, would be likely to result in lower output than *novel, unreal, playful*, problems.

Within the research here all the problems were based on descriptions of accidents. In the past most research has been based on playful problems such as; *find uses for a coat hanger*. Thus the problems in the research here were of a *serious* nature when compared to the typical problems used in brainstorming research. While all subjects would probably regard the problems as serious, the *relevance* of the problems would have been highest among the government and industry advisers, due to their professional interest in safety. With these two points in mind, the problems used in the research here would be expected to yield a lower amount of ideas than typical brainstorming research problems, and that this effect might be pronounced for those subjects of greatest expertise. Providing this effect had an equal impact on both the untrained and trained groups then the *comparison* of trained and untrained subjects would be unaffected. Unfortunately this may not have been the case. The enhanced performance in the trained groups was hypothesised to be due to the creative thinking training. One of the main mechanisms of successful operation of creative thinking techniques is to assist subjects to break from dominant ideas. These ideas have become dominant through familiarity and repetition. Overcoming this dominance may be more difficult with highly relevant problems. For experts, these problems have the potential to evoke a strong link to an *established* means of dealing with this type of problem. Strong linkages of this kind would seem to be potential barriers to the development of many *alternatives* to a problem. This would indicate that finding a training effect is probably more difficult using highly relevant problems, and therefore a reduced effect among experts is understandable.

In some sense the problem-relevance effect is consistent with some of the findings here. Untrained subjects perform at a similar level, whether they had a strong professional involvement with safety problems (health and safety practitioners) or had no particular past experience with safety (undergraduate students). However once trained in creative thinking methods, there were large differences between these two types of subjects. The undergraduate students, who were less involved with safety issues clearly outperformed those subjects with careers in safety. This does not show that the relevance of the problems was the reason for this effect, as there were other obvious differences between the groups, such as age for instance. While the effect is not proven as such, the effect problem-relevance was visibly apparent during the training with the government safety advisers. During the training the subjects seemed to be responding very well to the techniques and the exercises seemed vigorous, enjoyable and productive. At this stage the exercises were non-safety exercises and so had no particular relevance to the subjects. When the training was over, the assessment involved safety problems; problems that were of *direct* relevance to the subjects. The change in performance was visible; they seemed much more restricted and less fluent. There could be a number of potential explanations. For instance, tests that people are accustomed to are usually assessed based on *rightness* rather than the number of alternatives. While the instructions in this test emphasised developing options, it's probably reasonable to suggest that a focus on *rightness* in a testing situation is somewhat inbred in our culture. However, one would think this would apply equally to the other subjects, such as the undergraduate students, in fact, one could imagine that this effect would be stronger with the undergraduates who are accustomed to completing tests. An alternative explanation may be that this type of effect *combines* with the problem-relevance effect. These subjects have substantial experience in the field of safety and are accustomed to there being a *right* answer for these particular problem situations. With experience possibly comes a learnt paradigm that is difficult to move away from and then this effect is compounded by the pressure of a test. While similarly subjected to the pressure of a test, the novices may be less bound by preconceptions about what would be an appropriate set of solutions.

It would seem that how the subjects relate to the problems would have affected the relative outcomes of the training. This leads to something of a paradox. Experts have more knowledge about potential solutions, however this knowledge may be an impediment to thinking of a range of solutions.

6.1.10 Summary of the Issue of Generating Solutions

Increasing creative performance in the area of generating solutions to safety problems seemed to be mainly influenced by creative thinking tools rather than knowledge or information about safety. Evidence of this was in form of data that showed how groups with safety education and experience performed no better in terms of generating alternatives than those without this type of experience.

In contrast to the lack of influence of specialised knowledge, training in creative thinking techniques lead to substantial improvements on the task of generating safety solutions. The increase in generation of alternative solutions was accompanied by either, a maintenance, or possible improvement, in the proportion of safe place solutions. This indication of a positive relationship between quantity and quality is in keeping with Osborn's (1957) suggestion that the relationship should be a positive. While some studies have confirmed this theory (Parnes 1961), others have found no relationship (Parnes 1959) but more commonly noted has been an inverse relationship (Weisskopf-Joelson & Eliseo 1961; Parloff and Hanson 1964; Szymanski and Harkins 1992).

There were wide differences between the safety expertise of the groups. However expertise did not seem to lead to better generation of alternative solutions to safety problems. The apparently benign effect of greater expertise when generating solutions was not so clear when the effectiveness (proportion of safe place solutions) of those ideas was examined. There was some evidence from the study that those with no safety education or experience generated less effective solutions when analysed against the preferred hierarchy of control. This difference was only significant for one of the individual cases and not for any of the cases where people worked in teams. Overall, the evidence is not as clear as for the basic generation of alternatives, but there was no strong evidence to say that safety education and experience had a bearing on the generation of a greater proportion of safe place solutions.

Knowledge about safety theory has been well promoted in the quest for improved injury prevention abilities, however little attention has been paid to creative thinking skills. The research showed that creative thinking tools were an effective way to improve the generation of solutions to safety problems. The training led to large increases in the number of solutions with no reduction in the proportion of safe place solutions. The net result being large increases in the number of safe place solutions.

6.2 Prioritizing Effective Solutions to Safety Problems

The prioritization of potential solutions was the third key variable. From the examination of this issue there are a number of points for discussion.

6.2.1 The Effect of Creative Thinking Training on the Prioritization of Solutions: Why Effective only for the Engineers?

The creative thinking training seemed to benefit the engineers (both individually and in teams) in terms of the prioritization of solutions. However the same training seemed to have little effect on the technology students, industry advisers, or government advisers.

While there was an age and work specialisation difference between the engineers and the two groups of advisers, these factors were not a point of difference between the engineering and technology students. Yet, the training appeared to have a more substantial effect on the engineering students than on the technology students. Engineering students were in fourth-year and the technology students were in first-year. The most obvious difference is the education level; either the engineering education itself, or perhaps more likely, the health and safety component of the engineering education. Experiments in this research showed that those of greater expertise in safety performed better at the prioritization task. Given this result it seems as though the health and safety education within the engineering course would be an influential factor in the difference between the engineering and technology students. Therefore the possible explanation for their better response is that the creative thinking training can be effective in improving prioritization provided there is some basis for understanding the prevention methodologies. The training facilitated better decision making given a basic level of understanding of prevention theory.

Even with a basic level of understanding why would the creative thinking training improve the prioritization of safety solutions? It seems as though the creative thinking skills improved the handling of information in decision making tasks. The training emphasised the consideration of possibilities. The training emphasised that options that immediately appear silly or unwise may hold some value and perhaps should be considered. The highest ranking options in the prioritization task generally attack the source of the hazard by proposing an alternative way of achieving the job at hand. For many, perhaps these ideas are easily rejected. But the longer these options can be held within the realm of possibilities then the greater their chances of ultimate selection. The emphasis in the training of delaying judgement and considering seemingly weird possibilities can help keep the system-changing style options alive until their benefit becomes obvious. In this manner, it could be predictable that creative thinking training would enhance the prioritization of solutions.

The question remains as to why the creative thinking training would *not* have this effect with the industry advisers and the government advisers. Both these groups have the expertise to recognise the value of the system-change options. One reason, was that when working in teams both the industry and government advisers prioritized the options with reasonably good correlations with the optimum prioritization and so an improvement following the training could not seen. As individuals this reason did not apply to the same extent; untrained their scores were low enough to allow an improvement following training to be evident. However as mentioned, there was no improvement in prioritization for these groups following the training in creative thinking. While with the engineers, creative thinking seemed to facilitate better prioritization based on their basic understanding of safety, the same training provided no assistance to the industry and government advisers on the same task. Potentially given their extensive experience in the area, the advisers were less apt to accept an alternative approach to the selection of solutions. While creative thinking improved the generation of ideas for all subjects, maybe this aspect of thinking is far less bound by preconceptions. Perhaps years of experience provide greater restriction to the *prioritization* of good ideas than it does for the *generation* of ideas. Conceptually, prioritization of solutions, is much closer to actual implementation than is the generation of alternatives. Therefore, the learnt paradigms about what is successful, and even practical, are brought to bear to a greater extent and stifle the consideration of the potential effectiveness of ideas that involve changes to the system.

6.2.2 Novices and Experts Prioritizing Solutions

In decision making, expertise in accident prevention was shown to be important. There were significant differences in prioritization of solutions depending on their level of safety expertise. Given a list of options that had already been created, the results showed that those with greater specialist understanding of safety tended to adopt solutions nearer to the preferred, safe place, end of the hierarchy of controls.

However training in hazard management did not improve this measure for the government safety advisers. No significant improvement in performance was measured after two days of training designed to improve the ability. As mentioned, it was difficult to measure an effect for the training in the team work here as the teams in the untrained group were already reasonably good at the prioritization task. However there was some scope for improvement in teams, and ample for individuals where no change was also noted. Possibly the test was not sufficiently sensitive to measure such a change or that training to improve abilities like this needs to be more substantial. Two days of training does not necessarily form a substantial change in the concept of understanding safety compared to years of experience. While the training may have enhanced the subjects skills in some particular areas, the general philosophy of safety would hardly likely to be altered by such a small exposure to training. Interestingly it has since been shown that a five-day health and safety representatives course (of similar content) can achieve this type of change among health and safety representatives (Culvenor, Cowley & Else 1996). However, health and safety representatives are part-time in an OHS role and have had much less experience in the field than the government advisers studied in this project.

6.2.3 Summary of the Issue of Prioritization of Solutions

The results indicated that the ability to prioritize potential solutions to safety problems was related to the level of expertise in the area of safety. However, no improvement was noted in the ability to prioritize following a short hazard management training program. To put this in perspective though, the training program was applied to a group of subjects with an extensive experience in the area, and thus represented a small addition to their body of knowledge. It may be true that the same training program applied to another group would result in a more positive effect on this test (as has now actually been shown elsewhere; Culvenor, Cowley & Else 1996).

Training in creative thinking seemed to have a positive impact on the ability of the undergraduate engineers to prioritize safety solutions. However no such effect was noted for the industry advisers, or government advisers. Creative thinking training was a useful intervention for improving prioritization where there was a basis for understanding the mechanisms of safety via the safe place approach. The engineers had the benefit of education in this area but the technology students had not had this type of education. While their untrained performance was already high in teams, and thus the results are somewhat inconclusive, the industry and government advisers obviously were armed with contemporary knowledge of prevention methodologies and yet the training failed to assist them to better prioritize solutions. It seems possible that to make use of the creative thinking skills for prioritization, a basic understanding of prevention methodology was necessary. Conversely those with high level of expertise did not benefit from the creative thinking training in terms of their ability to prioritize solutions. For these experts, the widening of perspective generated by the creative thinking training may be limited somewhat by an intimate knowledge of what is practical.

6.3 Implications for the Training Assessment: Measuring Paradigms

Evaluation of hazard management training, if undertaken, seems often to evaluate the effect of the training by measuring what the participants perceive as the value of the training. For example training participants might be asked whether the training fulfilled their expectations, or they may be asked to estimate there own learning achievement. These evaluations measure the effect of the training based on the perception of the those attending. Objective evaluation usually takes longer than self evaluation and so is uncommon in short training sessions. Methods for assessing such courses in health and safety appear to be unavailable

For this project the intention was to evaluate the effect on performance effect rather than the perceived effect. The tools used in this project relied on measuring performance on various tasks rather than a self-reported perception of the value of the training.

The first part of the evaluation tool tested the generation of solutions to safety problems. From this test, two variables were drawn. Firstly, the number of alternatives generated in the given time and secondly a subjective evaluation of the effectiveness of those alternatives was make by classifying as either safe place or safe person in nature. These measures were applied to individuals and to teams. This type of test is similar in style to the general model of creative outcome testing, as suggested by Guilford (1950). The tests here exposed the subject to a situation and required creative effort to solve a problem, given certain instructions and a time limit. The test requires creative thinking, and seemed to show up some weaknesses with relying on expertise as precursors of effective problem solving. The tests showed that those who might have appeared to be in a much better position to generate solutions to safety problems were no better than comparative novices. While Tudor (1992) found that experts were superior in developing solutions and the potential effectiveness of those solutions, few other studies seemed to have compared experts and novices on the generation of alternatives.

The second part of the test measured the prioritization of safety solutions from a given list of options. The purpose of the test was to evaluate the subjects' tendency to recognise the potential of solutions nearer the preferred safe place end of the hierarchy of controls in preference to safe person controls.

The prioritization tool proved to be an effective tool to provide a simple and fast measure of conceptual knowledge of preferred controls. The test provided a measure of the extent that subjects adopted the safe place paradigm.

The assessment tools provided a way to undertake objective assessment of training without imposing too great time constraints. The prioritization tool especially, took a short time to administer and discriminated between various levels of safety expertise levels. In this way the tool could be applied to training either prior to training as a needs analysis or following training as an evaluation of the effect of the training on the actual performance of subjects. Given that the test seems to be able to make an assessment of the strength of the safe place paradigm then it seems reasonable that tests of similar style but different content could be used to assess other types of culture changes.

6.4 Messages for Risk Control in the Workplace

The results support the philosophy of consultation as a mechanism for workplace health and safety problem solving. Consultative processes imply that those at risk may be well positioned to develop risk control solutions. The reasons for this are probably more based in issues such as ownership and information, however the research here indicated that those without particular safety expertise can play a useful role in solution development. Specialists would seem to offer no advantage over novices when the task is to generate alternative solutions to a safety problem. While it may seem intuitively logical to involve specialists, or to attempt to improve the skills of those involved to be closer to the specialist level, it may be more profitable to concentrate on the enhancement of creative thinking skills. Creative thinking training was shown to substantially improve the ability to generate solutions to safety problems. Once solutions were developed and there were decisions to be made then expertise came to the fore. At this point novices appeared not to have the ability to prioritize solutions as well as those with safety expertise. These findings suggest that in an organisational setting, the support and coaching of safety experts would be worthwhile to maximise the effectiveness of solutions adopted and implemented.

Despite teams having a strong popular connection to creative efforts, research studies have persistently shown them to be less effective than individual work. Some of these studies evaluated the perception of effectiveness of the subjects who took part. These evaluations show that teamwork is perceived to be effective. It seems that, at least for the moment, teams are here to stay; they remain popular among those involved and are a growing feature of organisational structures. With the great body of evidence showing their ineffectiveness in creative tasks there's obviously a great need for creative methods that support the team way of working and improve its effectiveness. The research here was undertaken with this in mind and evaluated the effect of the creative thinking training in both individual and team mode. The creative thinking training was shown to improve the creative performance of both individuals and teams.

6.5 Discussion Summary

Knowledge about accident prevention appeared to have no statistically significant apparent effect on the ability to generate alternative ways to handle safety problems. There is some evidence to suggest that knowledge may play a role in focussing the alternatives toward safe place solutions. However the trend for higher knowledge to focus alternatives toward safe place solutions was isolated. The effects with regard to creative tasks and decision making tasks seem to be generally the same for individuals and teams.

In the strategy for the prevention of mechanical equipment injures, the National Commission highlighted the need for '.. *new approaches to engineering/technology safety measures and their incorporation into the design of equipment'* (NOHSC 1990c, p. 14). For the development of *new approaches* to safety problems, creative thinking training seems to hold great promise. A short training program in creative thinking lead to a substantial increase in the generation of solutions to safety problems. This effect was equally apparent for individuals and teams and was demonstrated with a range of subjects.

The logical step following solution development is prioritization and application. The National Commission commented on the need for '*... greater application of known engineering/technology safety measures ... and measures already in the workplace*' (NOHSC 1990c, p. 14).

The application, or prioritization, of safety measures seemed to be a skill of a differing domain to that of the generation of solutions. Safety expertise was an important factor in determining how well subjects were able to prioritize given sets of solutions for a set of safety problems. This also was equally true for individuals and for teams. The creative thinking training had a worthwhile impact on the prioritization of solutions for the engineers, but for all other groups there seemed to be little effect. Creative thinking training would seem to have the potential to improve prioritization by expanding the range of possible solutions that subjects considered for a given problem. This may lead subjects to consider options normally rejected. For this process to operate with any success though there needed to be a basic understanding of prevention methodology, and yet paradoxically when experts were trained in creative thinking there was no effect perhaps due to solidly embedded paradigms about the typically successful ways to manage safety problems.

In summary, the generation of solutions and the subsequent prioritization of those solutions according to their potential effectiveness seemed to be relatively distinct activities relying on different sets of abilities. Generating solutions seemed to be best improved via the enhancement of creative thinking skills. Creative thinking also had some impact on the prioritization of solutions, however the prioritization of solutions seemed to be a function of the level of safety expertise.

Chapter Seven

Conclusion

7. Conclusion

Each year in Australia many people are affected by workplace injury and disease. In addition to the burden of pain and suffering, there are substantial economic consequences. The Industry Commission (1995) estimated that the total cost of occupational health and safety failure was $20,000M per annum. This places the cost of workplace injury and disease at a figure approximating 5% of GDP and a magnitude greater than the Gross Farm Product. The imperative for change and the opportunities to be realised are clear.

The initial focus for this work was the prevention of mechanical equipment injury. Mechanical equipment injury is involved in around 28% of workplace injures and most workplace fatalities (80%). With respect to engineering as a means to prevention of mechanical equipment injury, the National Occupational Health and Safety Commission (1990c, p. 14) pointed to the need for new approaches and to better application of existing technologies. The research here focussed on these two themes; generating new solutions; and the application of known solutions.

As noted by the National Commission, the prevention of mechanical equipment injuries shares a common conceptual framework with prevention in general. Therefore the study was broadened to examine the themes above in a wider context. This research took the challenge of how to better facilitate safe place design. Education in hazard management is a logical way of improving design and engineers are a worthy target of these suggestions. However, this education for engineers has been problematic and so the aim of this study was to investigate a supplemental, innovative way of improving safety design.

The hypothesis was that training in creative thinking would be effective in improving the ability to design for safety. There seemed to be a natural link between creative thinking and safe design. Contemporary models for prevention have as their priority the elimination of hazards. This demands an examination of assumptions about the hazardous system which implies a logical role for creative thinking in facilitating this change of paradigm.

The creative thinking technique chosen was the six thinking hats model (de Bono 1985) that embodies many accepted principles of creative thinking. Subjects were undergraduate engineering and technology students, postgraduate hazard management students and a group of government employed safety advisers. The assessment of the training effectiveness was in accordance with established principles in the assessment of creativity, but adapted to safety theory drawing on the two themes mentioned above; *development* and *application*, of safety solutions. The assessment employed a set of fictitious safety case study problems. Subjects were required to suggest solutions to some problems, and for other problems were required to prioritize given solutions according to their potential effectiveness. Subjects worked on both tasks as individuals and in teams of three. The variables drawn from these tasks were threefold.

1. Generation of alternative solutions (number of solutions, idea fluency).
2. Generation of effective solutions (proportion of safe place solutions, idea quality).
3. Prioritization of effective solutions (correlation with standard rank).

7.1 Generation of Alternative Solutions

The training in creative thinking lead to substantial improvements in the generation of alternative solutions to the safety problems presented in the case studies. This enhancement was noted for subjects of varying education and experience, however the effects were largest with the undergraduate engineering and technology students. The improvement in the generation of alternatives following training in creative thinking is consistent with the view in literature that creative thinking is a learnable skill.

Improving education in safety seems to be an obvious way to accelerate the development of new approaches to safety problems. However the research here indicated that expertise in safety had little impact on the generation of alternative solutions to safety problems.

7.2 Generation of Effective Solutions

The study showed that training in creative thinking produced very few significant changes in the *proportion* of safe place solutions. In terms of the *number* of safe place solutions though, the impact was substantial. The maintenance of the proportion of safe place solutions combined with large improvements in the number of alternatives lead to a substantially increased set of potentially effective solutions. For instance the engineering students with the benefit of the training generated between 150-200% more safe place solutions than their untrained colleagues.

The research gave some indication that specialist safety knowledge may be important in improving the quality of solutions. For one case working individually there was a significant difference between the study groups on the proportion of safe place solutions. This was due to lower proportion of safe place solutions generated by the most novice subjects; the technology students. However there are a number of factors that mitigate the generalisation of this result. Firstly, this effect was only noted on one case out of three. Secondly, the other groups, while having varying expertise, generated similar proportions of safe place solutions. Thirdly, the effect was not apparant at all when working in teams. Furthermore the proportion of safe place solutions generated by individual technology students increased following the creative thinking training taking their quality of solutions nearer that of the other groups. Therefore the evidence of any effect of expertise on the proportion of safe place solutions was not substantial.

7.3 Prioritization of Solutions

For the engineers, the creative thinking training proved to be effective in enhancing the prioritization of solutions. However, this was not apparent for the other groups of subjects. It seems that there is some potential for creative thinking to impact on prioritization of solutions, but this may be less likely to occur where there is little understanding of prevention methodologies and where paradigms about practical solutions tend to be strong.

The research indicated that specialist safety knowledge had a positive impact on the prioritization of safety solutions. Those with higher levels of safety expertise were more likely to select solutions from the safe place end of the hierarchy of control. They favoured solutions relying on system changes rather than solutions relying on human behaviour. Consequently it seems that safety expertise plays an important role in hazard management at the decision making and control implementation stage.

7.4 Combining Creative Thinking with Hazard Management Training

In the study with the government safety advisers, the research showed that training in creative methods were an effective precursor to training in hazard management. The evaluation showed that alone, neither the hazard management training nor the creative thinking training had a substantial impact on subsequent test performance. However when creative thinking training was a precursor to the hazard management training, the generation of solutions by teams following both forms of training was substantially enhanced. The effect of the hazard management training seemed to be improved by the presence of the creative thinking training as a preliminary exercise.

7.5 Summary

The aim was to investigate an innovative way of improving the ability of engineers to design for safety. The research centred on the hypothesis that training in creative thinking methods would be an effective way to improve the ability of engineers to design for safety.

The key conclusion is that improving the generation of alternatives to safety problems can be achieved with creative thinking training. This training significantly enhanced the generation of alternatives with no loss in quality. Consequently the training lead to large increases in the output of solutions aligned with the safe place approach.

Making use of safety options requires an ability to distinguish between good and poor solutions. For the undergraduate engineers creative thinking training was an effective method to shift their paradigms about prevention toward the safe place approach. This effect was not noted for other groups. For the most part, the good prioritization of solutions depended on expert knowledge.

The findings support a model of empowerment in workplace risk control at the stage of generating potential solutions. Expertise in safety was not shown to be a prerequisite for this activity. However the process will require support from those expert in hazard management at the stage of selecting and implementing the most effective solutions.

The recommendations based on the findings of this research are that creative thinking methods be given greater primacy in education for those involved in the process of hazard management. These people may be engineers, where the enhancement of these skills might be best implemented via undergraduate education, or workplace-based hazard management teams who would benefit from this type of training in the workplace. The case of the engineers is especially interesting and indicates the potentially useful combination of the creative thinking training with their existing education in safety and health. The encouragement of creative thinking should be greeted by a receptive industrial climate given the growing need for innovation as a competitive priority.

In summary;

- Creative thinking training lead to an increase in the generation of alterative safety solutions. For example, the increase was approximately 100-150% for the engineers.
- The improvement in the number of alternatives was accompanied by no reduction in the proportion of safe place solutions.
- The set of solutions generated by those equipped with the creative thinking skills therefore contained a substantial increase in good solutions. For example; the increase in safe place solutions was approximately 150-200% for the engineers.
- Novices and experts seemed equally able to generate alternative safety solutions.
- Creative thinking training as a precursor to hazard management training proved to be an effective way to maximise the effectiveness of the hazard management training.
- When prioritizing solutions, subjects with the greatest safety expertise favoured solutions nearest to the safe place ideal.
- Creative thinking training had a positive effect on the engineering students' prioritization of solutions.
- **Creative thinking training was an effective way to enhance the generation and prioritization of safe place solutions by safety-educated undergraduate engineers.**

Tackling workplace injury and disease should be a social and economic priority. The opportunities for improvement are substantial and will be best realised with competent application of the safe place approach to prevention. It is vital for safety paradigms to move away from the distraction of behaviour-based concepts and toward the models of control at source and ergonomics. Creative thinking about safety can potentially facilitate this paradigm shift; potentially encourage *outside-the-square* thinking, which is after all the creative challenge presented by the hierarchy of control.

Chapter Eight

Further Research

8. Further Research

8.1 Engineering and Creative Thinking

The research here showed that a program in creative thinking training was effective in improving the solution generation by engineers. As mentioned in the introduction, the recent review of engineering education, *Changing the Culture: Engineering education into the future*, emphasised the importance of creative thinking skills.

> *There is a need for the introduction into courses at an early stage of greater attention to problem solving and the encouragement of creativity and innovation - knowing when analysis stops and synthesis starts. (IEAust, ATSE & EACED 1996, p. 7)*

Given the potential demonstrated here, research is indicated to determine the extent that engineering schools are including independent studies on creative thinking. Research is indicated to determine how these skills are integrated with other subjects. Research is indicated to compare the effects of the programs with the effects measured in this research.

8.2 Creative Thinking Application

Creative thinking training proved to have a positive effect on a test of safety design. The research showed a wider transfer of skills than has been shown in many other studies. However taking the transfer of skills to the logical next step, research is indicated to determine the effect of such training in an applied setting. Furthermore, given that the training proved useful on safety tasks then one would imagine that there would be improvement in problem solving in other applied areas. Therefore research is indicated to determine the broad effects of such training.

8.3 Safety Paradigms versus Actual Safety Recommendations

On the prioritization test, experts tended to favour the safe place solutions as an ideal. However, the test here was undertaken in an environment where subjects could put aside the constraints of practicalities and focus on what solutions would be most effective in an ideal sense. It would be interesting to know what relationship there is between the scores on this instrument and the type of solutions that would be recommended in a real work situation. Research is indicated to determine the relationships between safety paradigms and the types of approaches that would be recommended given a real problem.

8.4 The Poor Creativity of Experts

Training in creative thinking, without any reference or link to safety, lead to substantial improvements in the generation of solutions (up to a 200% increase in the number of safe place solutions for the engineers). While novices and experts alike benefited from the training, there seemed to be indications that experts may respond less well. Further research is indicated to test the hypothesis that creative thinking is more difficult in one's own field. If so it is indeed a conundrum worth solving. Some reasons that it seems likely to occur are discussed in this paper. If it becomes established that experts respond less well to creative thinking training then research is indicated to determine the barriers and to investigate the ways that these can be overcome.

8.5 Teaming-up Novices and Experts

The results showed that novices were equally able as experts to generate solutions to safety problems. It seemed then that training to enhance safety knowledge would be unlikely to lead to an improvement in this area. Training workplace teams in creative thinking would seem to hold more promise if the desired outcome is a greater ability to develop new ways to solve problems. However creative thinking training had only minor impact on the prioritization of solutions. This task was best accomplished by those with expertise in safety. This would suggest that expert knowledge is needed, whether via experts or input by training programs to enhance the expertise of workplace teams. Research is indicated to determine how the skills of novice and expert problem solvers can be best integrated.

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