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Engineering Creative Design

Introduction

Accidents, Human Error and Dominoes

Human errors are often the focus of accident analysis. The rationale has been that discovering and then removing these errors will improve safety. Defect removal is a common way to improve a system; find out what is wrong and remove or fix these faults.

'Browsing through old ICI files I came across a report dating from the late 1920's in which one of the Company's first safety officers announced a new discovery: after reading many accident reports he had realised that most accidents are due to human failing. The remedy was obvious. We must persuade people to take more care.' (Kletz, 1991)

Since that time company accident statistics have often been interpreted to conclude that human failing causes accidents. Statistics like these lead to improvements centred around removing the faulty human behaviour. Heinrich's domino theory defined a human error model for accident analysis (1959). The model has lead to controls that focus on behaviour modification. These controls are 'Safe-Person' controls by Atherley's definition (1978) and he contrasts these with 'Safe-Place' controls. Trevor Kletz suggests that the 'safe-person', 'domino' or 'behavioural' model is perhaps so popular because it may be comforting to managers to know that they have no role in accidents or their prevention (1991). Recently an Ansett 747 crash-landed in Sydney with the front wheel retracted. Aircraft manufacturers would probably be comforted to read that the investigators found the warning systems were operating (Burton, 1994). Are we to then conclude that this accident is due to an error by the pilot?

'Safe-Place' and the Energy Damage Model

The 'Energy Damage' model (Viner, 1991) recognises that injury or damage results from an exposure to an energy. This type of model promotes analysis of the system with a focus on change rather than a focus on improvement by analysis and removal of defects. The energy damage model seeks to identify the damaging energy and implement a control that ideally would eliminate that energy. This model promotes environmental or system changes to achieve safety. This type of change is a 'Safe Place' control. The model contrasts with human error models that seek to modify human behaviour to avoid exposure to hazards.

The safe-place controls are harmonious with quality management theory. Quality management promotes improvement by system changes rather than exhortation, encouragement or punishment (Deming, 1982). The science of ergonomics provides the theory to underpin the design of safe-place controls. Knowledge of human abilities, needs and expectations is a base for designing systems around human beings. Using a safe-place approach we might question the adequacy of the warning system of the 747 above. Sure the system was working, but amid the task of landing a plane, was the system good enough to alert the pilot?

Nowadays safe-place controls are considered more effective than safe-person controls (eg: Kletz, 1991; Atherley, 1978). The OHS profession applies the principles of safe-place controls particularly using design knowledge like ergonomics. Ergonomics aims to create an environment suited to people; places that are sympathetic to humans.

Why then do so many products, places, processes and equipment appear to be designed with little thought for the user (Deming, 1982)? Why then do the large majority (around ninety per cent) of equipment in Australian factories fail even to comply with guarding regulations (Viner 1993)?

How can we improve the way engineers and designers design? If designing is thinking then what is the thinking behind the popularity of safe-person, or behavioural, approaches to safety?

Breaking out of Existing Patterns of Thinking

We believe in truth and the idea of 'right and wrong'. Often we are uncertain whether something is true or false but we are certain that it is one or the other. *There was a mistake and everyone in science seemed to make it. They said that all things were true or false. They were not sure which things were true and which were false. But they were sure that all things were either true or false.* (Kosko, 1993) This belief leads to efforts aiming at improved systems to focus on what is 'wrong'; focus on removing defects. Removing defects, 'wrong things', seems logical in a 'right and wrong' world, if we remove the wrong, the right remains.

Imagine a world with no concept of ultimate right or ultimate truth. Improvement methods in such a world would revolve around 'change' rather than 'defect', or 'wrong thing', removal. In such a world we would strive to change systems to improve safety (and all other things), rather than remove the defects of the old system in the hope and belief that a better one will appear. Our thinking is bound by perception. Truth is thought to be found rather than generated.

Removing the bad features of a system won't always create the best new system. It is true that sometimes we can usefully compare a poor system with a better performing system and then alter the poor system to improve its performance. This method is useful but not sufficient. Critical and judgemental thinking are valuable and are effective methods as just described. This type of thinking is also valuable to avoid risks but too much criticism and judgement creates an aversion to change that is sometimes inhibiting.

Judgemental and critical thinking are easy and natural. It is easy to check differences between a suggestion and our well-learnt patterns. *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) This system appears vital to life. Everyday activities like walking across a road would require complex calculations if we had no experience of the situation or like situations. Recognising a pattern, in this case, safe road-crossing conditions, allows us to cross the road The system is useful and vital but not complete.

Our brain shapes itself with the information allowed in, organising information into patterns as a landscape organises itself into rivers and streams. Brains are patterning systems much like a landscape. Brains are self-organising systems (de Bono, 1971). Well-learnt patterns, 'deep rivers' in the landscape, are difficult to change. We check new information or different ideas against the well-learnt pattern and either channel it down as the 'same' or reject it as 'wrong'. The different information needs to be substantial before changing an opinion, a 'pattern'. This self-organising system is naturally reactive rather than creative.

Creative and non-judgemental thinking are not easy and not natural but they are worthwhile additions to critical and judgemental thinking. Stating the value of creative thinking is nothing new. Who says creativity is bad? However useable methods and mechanisms are necessary to change the system; simply encouraging people to sometimes be creative and non-judgemental is asking them to change without offering a method. The desire to be creative is insufficient since we remain bound by an un-creative, reactive brain. We need a method to break out of existing patterns of thinking.

New Tools for Engineers

OHS education for dedicated OHS practitioners is insufficient on its own. Safe-place controls implemented at the design stage are desirable but OHS practitioners seldom have control of design. Engineers and designers are able to affect design in this way. OHS education for all engineers and designers is tempting and probably necessary to some degree. However valuable OHS education would be for all engineers and designers, implementing a program of this type is a major undertaking. We propose an alternative, or addition, that is easy and quick to learn and offers other benefits. We propose a thinking method designed to encourage creativity.

Creativity: Who Needs It?

The missions of Du Pont's Centre for Creativity and Innovation are to *'...accelerate progress toward our corporate vision through education in creative thinking techniques, application problem solving or opportunity searching in-house and with customers, and helping line managers foster an environment for innovation.'* (Tanner, 1992) Du Pont commit to teaching creative thinking methods and to the right environment for creativity.

Dr Sidney Harman, Harman Industries' CEO, says *'The challenge to management is to create an environment where that untapped inventory can be released.'* Dr Gerald Laubach, President at Pfizer, also implicates management in the creative process, *'Senior management, however, has to create not only a zest for innovation but also a recognition that innovation is valued and will be* *rewarded.'* (in Young, 1987). Thomas J. Watson Jr., former chair of IBM, believes an environment for creativity is vital while Apple CEO, John Sculley, says creative people must have the right environment including a little controversy and *'anarchy'* (Geber, 1990).

Gib Akin, Associate Professor at the McIntire School of Commerce, University of Virginia, suggests a culture change is vital to promoting creativity among engineers. Engineers and engineering prefer to *'...proceed in predictable, prescribed ways, relying on rational, scientific methods of solving problems and maintaining control'* (1988).

Specific training in creativity is now recognised as important. Between 1986 and 1990 the number of American organisations with one hundred or more employees that offered creativity training doubled from sixteen to thirty-two percent (Hequet, 1992). We don't really know if this creativity is similar to Edward de Bono's programs or perhaps like William Gordon's Synectics (1961) or maybe variations of the brainstorming technique invented by Alex Osborn (1963) or some other method but the importance of creativity has been recognised.

Corporate Creativity in Japan

'The geniuses are kicked out'! Tadatsugu Taniguchi, Molecular Biology Director at University of Osaka, says the Japanese education system promotes evenness across a range of subjects and thus overlooks some individuals brilliant in special areas (in Bylinski & Moore, 1987). Japanese societal, cultural and education systems tend to obstruct creativity (Bylinski & Moore, 1987) and are the background to calls for creativity such as from the White Paper by the Japanese Science and Technology Agency (Anderson, 1985), but are Japanese and their culture impossibly un-creative?

Ralph Gomory, Senior Vice-President at IBM, suggests that the Japanese 'uncreativity' is really wishful thinking by the West (Bylinski & Moore, 1987). This could be so; perhaps Japanese have largely intentionally ignored creativity. Japanese industry made good progress making technologies developed by others into marketable and affordable goods; as the Science and Technology Agency's earlier report said *'...up to now Japan has taken foreign science and technology, improved and developed it in a response to social and economic needs...'* (Anderson, 1984).

Early in the 1980's the Japanese recognised the need for more creativity. Did it happen? Yes. *'During the 1980's, however, innovation became Japan's new industrial slogan, imitation was no longer assuring corporate survival. Fierce global competition and the rising yen forced companies to find ingenious ways to recycle technologies into new products.'.* (Tatsuno, 1990) Sheridan Tatsuno goes on to say, *'We are witnessing a historic transformation. Japan is turning away from the West and reexamining its own cultural roots. It no longer seeks to copy the West, but to develop its own forms of creativity.'* The catch-up game is complete and Japanese are beginning to invest in creativity.

Our Proposal

We propose that training in thinking and creativity can be a useful supplement to education in discipline specific areas (for example OHS or engineering). We propose that training in thinking and creativity will improve and change the way engineers design and lead to more safe-place systems.

Study Outline

The thinking and creativity training we chose to test that could lead to improved OHS design is Edward de Bono's Six Thinking Hats® method (de Bono, 1992). This reference is the training manual that contains the method as taught. The published book *Six Thinking Hats* (de Bono, 1985) is readily available and explains the system although there have been some additions and changes to the exact nature of the method.

Dr de Bono originated the term 'lateral thinking'. Lateral thinking is a series of techniques for developing new ideas. The techniques provide a way to escape the un-creative system. Lateral thinking methods are for *driving* new ideas not merely *releasing* them as in methods such as brainstorming. Specific methods for thinking of new ideas quickly, and on demand, are useful but how do we make use of these ideas? The un-creative system often finds little benefit from these ideas. Judgemental and conservative thinking are necessary and very valuable but can be inhibiting if used all the time. It appears we could benefit from a framework for thinking to escape from the judgemental thinking mode some of the time, especially when developing and considering new ideas.

Early in the 1980's Dr de Bono invented the Six Thinking Hats® method. The method is a framework for thinking and can incorporate lateral thinking. Valuable judgemental thinking has its place in the system but is not allowed to dominate as in normal thinking. Dr de Bono organised a network of authorised trainers to introduce the Six Thinking Hats®. Advanced Practical Thinking Training (APTT), of Des Moines, USA, license the training in all parts of the world. APTT organise the trainers and supply the only training materials written and authorised by Dr de Bono. In 1993 John Culvenor was trained to teach the method by Dr de Bono.

Organisations such as Prudential Insurance, IBM, Federal Express, British Airways, Bank of Montreal, Motorola, NASA, Honeywell, Du Pont and Nippon Telephone and Telegraph, possibly the world's largest company, use Six Thinking Hats®. To date no-one seems to have tested and quantified the effect of the method.

Six Thinking Hats®

The six hats represent six modes of thinking and are directions to think rather than labels for thinking. That is, the hats are used proactively rather than reactively.

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

These words describe the kind of thinking we do now! There is no new content in the type of thinking (except lateral thinking that can be part of the Green Hat). It is the structure of thinking that the system alters. A jumbled heap of building materials is not a building; yet the content is the same. A dismantled Eiffel tower would be an unimpressive heap of steel sections and rivets. Adding more material to the heap, or information to our thinking, would not make it any better. With structure that heap becomes a famous landmark. Adding information and sorting the information into boxes with analysis does little to build a useful structure. Structures and specific tools for thinking turn muddled heaps of information into landmark thinking. The Six Hats method attempts to build our jumbled thinking into a powerful structure.

The method encourages a full range of thinking. Often criticism and judgement dominate our thinking. There is nothing wrong with criticism and judgement; they are essential parts of thinking. Flour is an ingredient of a cake; but a cake made entirely of flour is not a cake. Flour for cakes and criticism for thinking are good, valuable and essential ingredients, but are not sufficient. In thinking, often our cakes are a little too floury. This is natural and sensible; it is prudent to point out risks and dangers in ideas; the 'devil's advocate' role. The Six Hats method allows full ranging thinking because there is time for looking for benefits, time for thinking for new ideas and time for feelings and facts, without the fear that risks will go unchecked because there is also a time for focussing on criticism. Time is available for focussed thinking in a number of modes rather than trying to think about everything at once. Blue Hat thinking manages the whole process. The Blue Hat is the control hat; the Blue Hat is the 'thinking about thinking' hat.

The Six Hats method encourages parallel thinking as against adversarial thinking. Observe our parliaments, law courts, meetings and general discussions to witness to-and-fro lawyer type thinking all around. For example, consider two people, Kelly and Pat. Pat has developed and supports a proposal that Kelly genuinely believes is a poor proposal. It appears responsible for Kelly to take an adversarial position. Kelly wants to prevent this proposal proceeding. If Kelly sees a few positive aspects, there is no point bringing them forward; the reverse is true for Pat. Exploration of the proposal or subject suffers because Pat and Kelly adopt adversarial positions. With the Six Hats everyone in a group thinks in the same direction at any one time, if initially Kelly thought the proposal was a poor one there is no harm exploring good points under the Yellow Hat because everyone, including Kelly, knows that the Black Hat at a certain time will allow a thorough examination of the risks. Six Hats attempts to encourage exploration by parallel thinking.

The method promotes fuller input from more people, in de Bono's words it *'separates ego from performance'*. In the example above, if Kelly truly believes the proposal is poor, will be defeated, will be dangerous, or whatever, ego restrains Kelly from bringing forward any good points. Kelly doesn't want to promote a proposal that ultimately fails; Kelly, like most of us, wants to back winners. 'Backing winners' involves making early judgements and seeing them though whereas the Six Hats system allows Kelly to put forward benefits under the Yellow Hat even though there appears initially to be no future for the idea. Everyone is able to contribute to the exploration without denting ego's as they are just using the Yellow hat or whatever hat. The Six Hat system encourages performance rather than ego defence. People can contribute under any hat even though they initially support the opposite view. We've presented a rather poor image of Black Hat thinking; this is not intentional as the Black Hat is probably the most valuable hat as it avoids risks and dangers but we use it to illustrate the system as it is the most abused mode of thinking.

The key point is that a hat is a direction to think rather than a label for thinking. The key theoretical reasons to use Six Thinking Hats® are to:

encourage parallel thinking,
encourage full spectrum thinking,
separate ego from performance.

Parallel Thinking

Parallel Thinking represents the thinking outcome of using the method. While the hats concept explains the technique (vital for using the methods) Parallel Thinking evokes a mental image of the result. Parallel Thinking describes the kind of thinking created in the program.

Targets

We are targeting engineers and OHS practitioners. OHS practitioners are being studied as a benchmark. The OHS practitioners were the first group studied. The group were first and second year students of the Occupational Hazard Management Graduate Diploma at the University of Ballarat (OHM). Forty-eight people volunteered for Parallel Thinking training in the research program. APTT, suppliers of the training manuals, supported the research and donated all the manuals used during the research.

We divided the subjects randomly into a control and experimental group. The control group completed an OHS design test before the training and the experimental group took the test after the training. The test required subjects to generate solutions to accident case studies. Subjects worked on the first three case studies individually and then in teams of three for the remaining three case studies.

Case	Task	Mode	Time Per Case
One, Two & Three	Create Solutions	Individuals	Six Minutes
Four, Five & Six	Create Solutions	Teams of Three	Six Minutes

The training took place on a the first Saturday of the graduate student's mid-year three week block of lectures. The training began at 8:30am and concluded at 5pm.

Later groups were forty-two final year students in the Bachelor of Engineering Degree (BEng) at the University of Ballarat and nineteen first year students of the Bachelor of Technology Degree (BTech) at the University. The Engineers undertook training in one day as for the Hazard Management students while the Technology students took the training over five weeks.

Safe-Place / Safe-Person: Directions to Focus Attention

We based our analysis of 'solution quality' on categorising solutions as safe-place or safe-person. What is a safe-place solution and what is a safe-person solution? Are these valid categories? Safe-place and safe-person solutions are directions rather than definitions. Safe-place solutions stem from models like the energy damage model that direct action toward changes to the risk environment. Typically these solutions will involve equipment, process or product changes. Safe-place solutions tend to eliminate hazards and rely little on prescribed human behaviour to make them work. They do not rely heavily on appropriate behaviour of the potential victim (person at risk).

Safe-person solutions typically use behavioural and administrative procedures to mitigate a hazard. These solutions tend to leave hazards in place. Encouragement of appropriate behaviour by people (especially those at risk) characterises safe-person hazard controls. Warning signs, protective equipment and safe-work procedures are examples of safe-person controls.

General Outcomes

Individuals and teams using Parallel Thinking outperformed the control group in the number of ideas they produced and the quality of those ideas, that is, a greater proportion of safe-place solutions (Table 1.). The table compares the performance of the Parallel Thinkers with the control group. The trends are similar for the OHM, BEng and BTech groups thus the results here are a combination of these groups.

Table 1. Summary Results: Improvement of Parallel Thinking Group over Control Group

	Individuals	***Teams***
Creativity Productivity	80% Increase	85% Increase
Creativity Quality		
Safe-Place Ideas	110% Increase	125% Increase
Safe-Person Ideas	45% Increase	50% Increase

Consistent Creativity

The change in thinking performance is consistent for the three different cases for individuals and for teams. Figure 1. and Figure 2. show the number of ideas generated by individuals and teams of three people working on OHS case studies for six minutes.

Figure 1. Individual Creativity

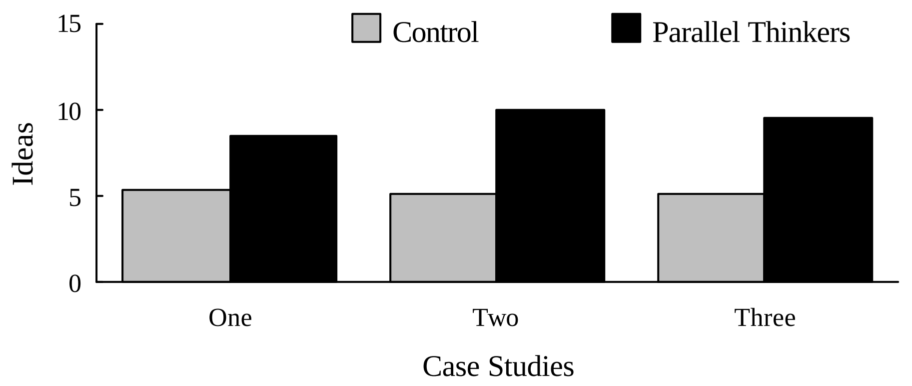
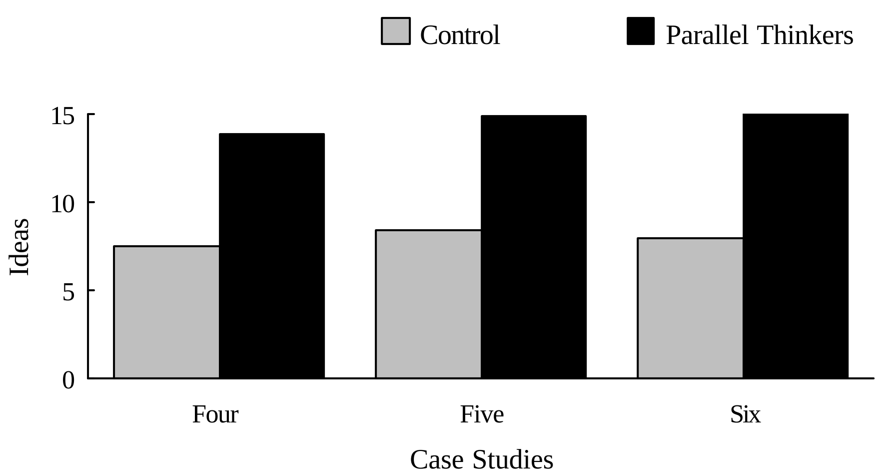


Figure 2. Team Creativity



Individuals created solutions for case one, two and three before working in teams of three people on case four, five, and six. The trend working individually and in teams is similar. Working alone, or in teams, subjects using Parallel Thinking generated more ideas on every case. The improvement over three cases working individually is approximately eighty percent while in teams the improvement is approximately eighty-five percent. The evidence suggests that the training increased the number of ideas that individuals and teams produce.

Thinking Quality: Improving Alongside Improvements in Thinking Productivity

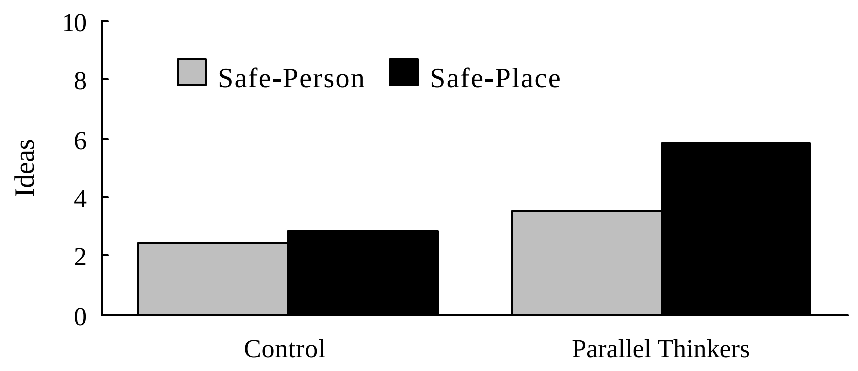
Parallel Thinkers Produce a Higher Proportion of Safe Place Solutions

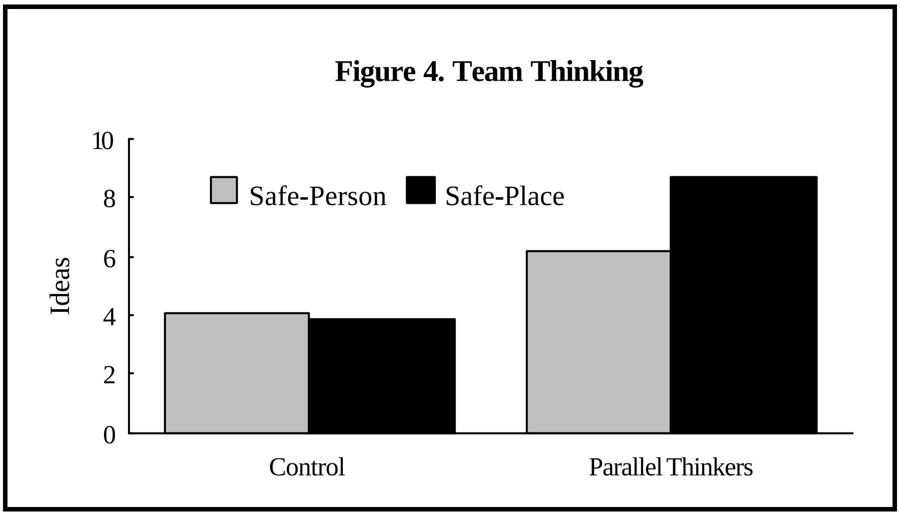
Producing more ideas is beneficial but what about the quality of those ideas? To measure this we classified each idea into two categories; 'safe-person' or 'safe-place'. These two categories correspond broadly to either end of the 'Hierarchy of Controls'. Some controls are clearly at one end of the hierarchy and are easily classified. Solutions near the middle could be in one or in the other so we developed a standard list to classify solutions. The solutions were classified without knowledge of whether they came from the control group or the experimental group.

Figure 3. shows the proportion of 'safe-place' and 'safe-person' solutions generated by individuals in the control and Parallel Thinking groups. The increase in creativity using Parallel Thinking (Figure 1.) comes with a simultaneous quality improvement. That is, the Parallel Thinkers produce a higher proportion of safe-place solutions (higher quality). While the control group developed about equal numbers of safe-place and safe-person solutions the Parallel Thinkers produced a higher proportion of safe-place solutions.

Figure 4. shows a similar trend in the proportion of safe-person and safe-place solutions when working in teams.

Figure 3. Individual Thinking



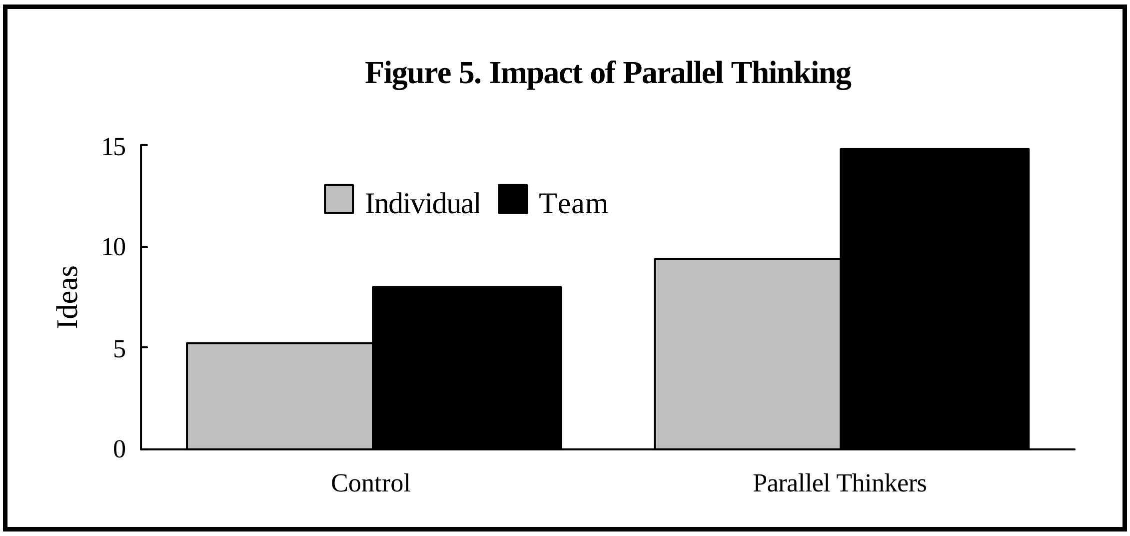


Impact of Parallel Thinking

Consider Figure 5. below, a graph of the average total ideas. An untrained individual produces about five ideas. When three people form a team we would hope that the output might be three times what one could produce. This did not happen. Teams of three untrained people generate only a few more ideas (about eight ideas). Teamwork does not appear to be as effective as we might suppose.

The last two columns show that three trained people generate about three times as much output (about fifteen ideas) as one *untrained* person (about five ideas) and one Parallel Thinker (about nine ideas) approximately equals an untrained team of three (about eight ideas).

Groups work if given a method. Parallel Thinking provides a structure so that three people can do three times as much as one.



Conclusion

Parallel Thinking improved the performance of OHS practitioners, final year engineering students and first year technology students on OHS problems. Using Parallel Thinking, their ability to produce alternative solutions increased; they produced more solutions in a given time (80-85% increase) and these solutions were higher quality.

These effects were similar for individuals and teams and were apparent in subjects of varying ability; from experienced OHS practitioners to near to graduation engineers and first year students with no OHS education.

The one-day training included no OHS information, guidance or education. The productivity of thinking increased with a simultaneous improvement in the quality or content of the thinking. Compared to the control group Parallel Thinkers generated more solutions and a higher proportion of safe-place solutions.

Individuals using Parallel Thinking generated as many solutions as teams of three people not using the Parallel Thinking. Parallel Thinking created a structure for effective team performance. Parallel Thinkers produced more solutions and these solutions were higher quality, that is, a higher proportion of safe-place solutions. The method worked with a range of ages, experience and education. We changed the structure of thinking and the way people interact without adding any information yet we improved performance on specific OHS problems.

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