2012 Kennedy-Wunsch Memorial Lecture

A chemical engineer in the pulp and paper industry - by Graeme Robertson

Introduction

I must thank SCENZ and IChemE for the opportunity to give this Kennedy-Wunch lecture. It is an especial honour because Professor Miles Kennedy was Head of Department during my time at Canterbury University and had a big influence on me. He was also the first chemical engineer to be elected President of IPENZ, something which gave me great encouragement.

It is almost 25 years since I left the pulp and paper industry, so this paper will concentrate on only two decades in its development: the 70s and 80s. The presentation will cover people and projects where I had some direct involvement. It is not a comprehensive list of the many contributions of chemical engineers to the industry. That will be followed by an account of several learning experiences from a completely different sector, where I worked with biologists and biotechnologists. Finally, I have added an extract on the nature of chemical engineers, from a paper given at 50th anniversary of the Chemical Engineering Department at Canterbury University in 1994.

The pulp and paper industry was my life for 21 years, from my first exciting interview with Warwick Olsen at Tasman pulp and paper in 1967 to my move to something completely different in 1988. The socialisation process which occurs when a fresh graduate begins a new job can be a profound experience, the effects of which persist throughout one's career. That certainly was the case for me at Tasman. The people who guided my first few years at Tasman, their work ethic, approach and values, had a big influence on me.

An even greater influence came from four years spent at STFI in Stockholm. The Swedish Forest Products Research Laboratories was at the time a centre of excellence, not only in Sweden. The Paper Technology Department of STFI was headed by Prof Douglas Wahren, who was also a head of department at KTH, the Royal Institute of Technology. He was awarded a Tappi Gold Medal in 1998, for “preeminent scientific and engineering achievements of proven commercial benefit”.

While the calibre of the research staff at STFI was very high, my subsequent career was influenced even more by my observations of the close relationship between the research scientists and engineers and the research users within industry. This was partly due to the traditional career path in Sweden. Upon graduation with an engineering degree (at age 25 or 26) a future industry leader would then spend several years at STFI before moving into a production role within industry. When STFI researchers went out on a mill visit, we were often invited to dine with the top management of the company. The dinner conversations, for example with a managing director or board member who was extremely technically literate and wanted to keep up-to-date with the latest research, were a heady experience for a young New Zealand chemical engineer.

I gather this emphasis on technical education for industry leaders was even more pronounced in Finland. In 2002, I visited a former STFI colleague working for Stora-Metso in Falun. The company used to be called Stora Kopparberg and had celebrated its 700th anniversary some 10 years earlier, but had just been taken over by a Finnish company. My friend said that when hiring engineers, his first choice would be someone from Finland. Not because his company now had Finnish owners, but because those Finnish engineers were significantly better educated. Is it a surprise that companies from Finland have become a dominant force in the global pulp and paper industry?

For a few years after I left the industry I maintained some contact, through lectures on paper machine pressing, drying and calendering in the University of Auckland diploma course in pulp and paper technology. That eventually lapsed as I found myself becoming out of touch with current technologies. For another 10 years or so, visiting printers trying to sell their services would occasionally be surprised by a 30 minute impromptu lecture on paper optics, but even those urges eventually waned. Now I'm very out of touch with the industry. That's why this paper is focused on the exciting 70s and 80s.

NZ pulp and paper in the 70s

At that time, pulp and paper was a rapidly expanding, dynamic and very exciting industry. We were one of the largest employers of chemical engineers in the country. There was no trouble in attracting staff, companies often had the pick of fresh graduates from the chemical engineering schools. In that, New Zealand was rather similar to Scandinavia where the industry was an even larger player in local economies.

The situation in the USA was very different. I remember reading a survey of undergraduates in a North American chemical engineering Journal, ranking the attractiveness of various sectors. Pulp and paper was near the bottom, somewhere around 32 out of 36 or so. This meant that the general technical standards within the New Zealand industry were very much higher than in the USA, despite our country's small size.

There are many examples of New Zealand chemical engineers who have made outstanding careers offshore. A few that spring immediately to mind: Peter Lee, who became research leader for International Paper, the world's largest paper company; Klaus Moller, who at one stage was one of only five staff of multinational Norske Skog to be named in their annual report; Bill Johnson who led Australia Newsprint Mills after a successful career at Tasman; and more recently Mike Odell, formerly with Valmet/ Metso and now managing the world's largest UWF (uncoated wood-free, or copier paper) machine in Portugal.

Others received international recognition while remaining within New Zealand. Stuart Corson was a long term advocate for the creation of PAPRO and the driving force behind its leading-edge mechanical pulping pilot plant. His words were probably listened to more attentively by industry leaders in Europe and Scandinavia than those in New Zealand.

The Kinleith mill

Although my first job was as a process engineer at Tasman, most of my time in the industry was spent at the Kinleith mill. This had started in the early 50s for the utilisation of the substantial forest plantings in the region. Its products were a mixture of exports (market pulp and packaging grades of paper) and import substitutes. By the mid-70s, it had seen frequent, incremental expansions. The result was a curious mixture. Some of the units (chlor-alkali, continuous digester, bleach plant) were leading edge technology. Others, for example five of the six paper machines, were relatively small and had been old technology when they were installed. No 3 Paper Machine, installed in '64, was in fact a 1920s model: technology very familiar to the papermakers who were making the decisions at that time.

By the mid-80s, Kinleith had become arguably one of the most complex mills in the world. In addition to a large sawmill and plywood mill, it boasted three pulp mills, three lime kilns, four recovery boilers plus assorted power boilers, and six paper machines. The paper mill produced more than 2000 different grades, few of them efficiently. For example, the two New Zealand companies producing laminates (such as Formica) could have imported their raw material at about one third the cost, had they been permitted. The production of such a difficult grade as saturating base paper in short runs at Kinleith was dreadfully inefficient.
I can recall having very mixed feelings in conversations with my former colleagues from Sweden: shame at the inefficiency (and occasional incompetent operation) of most of the Kinleith paper mill, but pride in those units that did perform well: No 6 Paper Machine, No 2 Pulp Dryer, and much of the pulp mill.

No 2 Pulp Dryer

The pulp dryers were the outlet for market pulp, usually sold in heavy, baled sheets. No 2 Pulp Dryer was commissioned as part of the expansion in the early 70s with a design capacity of 400 tpd, a figure seldom consistently achieved. It was a difficult machine to run well and eventually one of the mill's most capable production superintendents, Hank Kleyn, was given the task of improving its operation. Hank was sufficiently confident in his own skills and capabilities that he was not threatened by the continual probing, questioning and criticism coming from the fortunate process engineers brought into the team. One of these was Kit Wilson, another Canterbury graduate, with whom I particularly enjoyed working. The process engineers, design engineers and production superintendent all had a mutual respect which was an important factor in this team's success.

Even in integrated mills, pulp dryers are usually run by pulp mill staff. The more modern number two pulp dryer actually looked rather like a paper machine, but ran at about one fifth of the speed. There were two, interrelated problems. The machine was "dryer-limited", that is its production rate was limited by the capacity of the steam-heated dryer section. As well, operating efficiencies were low due to frequent sheet breaks, usually due to the high sheet moisture content ahead of the dryer.

Heat and mass balances over the dryer section showed it was working well. We worked back from the dryer, concentrating on the press section where water is squeezed from the sheet. We made encouraging progress, but the results were variable. Eventually we found that the scatter in results could be traced back to the moisture content of the sheet entering the press section. So we moved back up the machine.

The dominant factor affecting water removal rates in the forming section turned out to be the temperature of the sheet and the recirculating water system. This was well known from paper machine experience, but the effect at the slow operating speed of a pulp dryer was very much larger than we had anticipated.

Think of the machine as a large belt filter. As the temperature of the liquid phase increases, its viscosity drops, flow resistance is reduced and filtration rates increase. In this case, the fibre mat was compressible. During the last stage of water removal on the forming section, the forming fabric (= filter cloth) passed over several vacuum boxes, compressing the fibre mat. Because it was saturated this point, the moisture content of the sheet was directly proportional to its thickness. Increased temperatures softened the cell walls of the pulp fibres, increasing the compression and hence reducing the water content.

We realised the most sensible way to raise the system temperature was to reduce the input of cold water. This was achieved by dramatically increasing the recycling of process water. This proved to be possible at a relatively modest capital cost.

By continuing to apply basic principles, we were able to make further gains. Often these were the result of uncovering some rather surprising results and we enjoyed confounding visiting overseas "experts". The final result was a win on many fronts: production increased significantly and the specific energy consumption went down. Water usage dropped from around 20 m3/tonne to about 1 m3/tonne and the discharge of waste water almost ceased. To our delight, the drains ran dry. The machine became very efficient, with at one stage the highest production rate per unit width in the world.

It gave me a lot of pleasure to return to Kinleith some years later and see the continued improvements. It was still amongst the very best. After climbing over the machine for the best part of an hour I found myself standing beside the production superintendent, gazing at the pulp dryer in silence. He watched me, then admitted quietly "I love this machine" I knew exactly what he meant. Kit would have understood too.

Of course, the improvements didn't stop there. Kinleith currently has an annual output of 275,000 tonnes of market pulp. That's an average of almost 800 tpd and I understand its peak production rate is close to 1000 tpd.

Bark Extract Project

On national radio recently I listened to an interview about a Marlborough company called CarbonScape, describing an exciting new development. They had successfully produced high-quality activated carbon from waste pine sawdust. Back in the mid-70s we were producing high-quality activated carbon from sawmill waste at Kinleith. The work was an offshoot of the ambitious Tannaphen project to produce tannin adhesives from pine bark.

The project very nearly became a commercial success. Laboratory work showed that tannins could be extracted relatively easily from ground bark, even with hot water, and produced a useful adhesive. A pilot plant was built near the wood yard at Kinleith, to define the process and help select equipment for size reduction, extraction, phase separation, evaporation and spray drying. This led to a full-size commercial plant which in retrospect looked like a small pulp mill. A recycled disk refiner gave very efficient size reduction. The large belt filter used for counter current extraction had a lot in common with the wet end of a pulp dryer. It was followed by evaporators and a spray drier. The plant worked very well, yielding tannin-formaldehyde adhesives with excellent bond strength well suited, we thought, for particle board and plywood manufacture. The extracted bark had a ready market too, in horticulture as a component in potting mixes and mulches.

For particle board the glue had excellent water resistance. This was a real advantage over urea-formaldehyde resins, especially for flooring grades. The boards had a distinctive dark reddish colour which the marketing department were confident would be acceptable for flooring grade particleboard. The colour, however, did prove to be a serious problem. When flooring is laid down early in construction it can spend quite some time exposed to the sun. The greater absorbance of tannin-formaldehyde particleboard often led to severe warping under these conditions. The solution, to reduce absorbance by applying a coating such as a whitewash which could later be sanded off, was not at all attractive to customers.

For plywood, the colour of the adhesive was irrelevant. Tannin-formaldehyde glues, while producing superior bond strength to phenol-formaldehyde resins under ideal conditions, were very sensitive to the moisture content of the veneer. Dry areas caused a drop in bond strength, in the worst case leading to delamination of the plywood. The continuous veneer dryer used in the Kinleith plywood mill had great difficulty coping with the difference in moisture content between sapwood and the core of a large peeler log, so was notorious for large moisture variations. Moisture-sensitive tannin-formaldehyde glues proved to be inherently unsuitable for this application.

As we struggled with these problems, demand for the bark extract dwindled while sales of the extracted bark soared. Horticulturalists preferred a coarser product, which of course gave a lower yield and quality of extract. We watched plant performance slowly decline before it was shut down altogether. It was a sad end to what had been an exciting project.

Two species from one log

The two large mills in the central North Island, at Kinleith and Kawerau, had been built to utilise the massive resource of Pinus radiata in the Kinleith and Kaiangaroa forests. For a number of reasons, Pinus radiata grown in New Zealand has some very interesting properties. Fibres in the outer layers of a P radiata log, for example, are very different from those near its core. Basic density (kilograms of dry matter per cubic metre) may range from 300 or less in corewood, to more than 550 in outerwood. Such differences are not seen in trees grown more slowly. Corewood fibres on average are shorter, with a smaller diameter and wall thickness. It's almost as if there were two species present in one log.

While these facts had been known by foresters, their significance for papermakers was not appreciated until microscopist Dr Paul Kibblewhite at the Forest Research Institute tackled a major problem faced by the Caxton Paper Company in Kawerau. Their newly-commissioned No 3 machine was still, after many, many months, unable to meet specification for an important paper grade: one-time carbonising tissue (OTC). The problem was ‘pinholes’, tiny holes in the tissue sheet. When the sheet was coated with carbon black the holes allowed the coating to bleed through, causing unacceptable fouling of the converting machinery.

To make such a dense, lightweight papers, the pulp fibres are physically treated so the cell wall swells, becoming very flexible. This enables the fibres to collapse and bond one with another during the forming process. In this case however large, thick-walled fibres were resisting the treatment, forming small structures through which material could be washed out of the sheet. The offending fibres were coming from the bleached pulp sourced from Kinleith.

The Kinleith pulpmill agreed to run a trial to produce bleached pulp from ‘corewood’ (thinnings and top logs). In some ways the trial was a huge success: Caxton were delighted with the product. Unfortunately, pulpmill management neglected to tell the Kinleith papermill what they were up to. The result was a period of 24 hours of reject paper on No 4 Paper Machine. Its pulp supply had suddenly been boosted by a flood of thick-walled fibres as all the corewood pulp was diverted to Caxton. The pulp being supplied to No 4 Machine produced horrible fine paper, with a blotchy, lumpy formation.

Ultimately, this learning experience proved to be very important indeed for Kinleith. Corewood pulp was very suitable for fine papers, while the very coarse fibres in outerwood pulp made excellent packaging papers and certain specialty bleached pulp lines. The trick was to manage the flows.

That’s where a chemical engineer came in. Kit Wilson was given the task of analysing the confusing data available for the various fibre lines and presenting it in a form which could be readily understood by operations staff. Many of them met Sankey diagrams for the first time. Kit Wilson describes that as one of the most satisfying of his Kinleith projects.

The complexity trap

I've mentioned that Kinleith was a large, complex mill. At its peak, it was one of the most complex in the world. Production management in that environment was a huge challenge. Even with good instrumentation and computer systems, only a handful of people had the necessary knowledge and overview to cope with the complexity and make informed decisions. Chemical engineers were in their element here, comfortable with concepts of mass and energy balances and very good with data. It felt good to be in, or even on the fringe of, that small group. When we visited a mill overseas, their operations seemed very simple by comparison. That too felt good.

This was a subtle trap which I am sure acted as a barrier to change, at least among some production staff (well, at least for me!). Even those who had worked in different, simpler operations could be "sucked in" by the lure of this complexity, and miss the point.

Very much to his credit, the mill manager at that time was able to step back from this scene and strive for a reduction in this complexity. The future for such a large, capital-intensive plant lay not with flexibility but with efficiency, with long production runs which enabled the fine-tuning of machines and careful attention to costs. We could see that of course at our neighbouring mill. The newsprint machines at Tasman had been run that way since start-up, forced to be internationally competitive.

The removal of export subsidies and import protection during the economic reforms of the 80s meant that such a transformation was vital for Kinleith's survival.

Ship's ballast water

When I left the forest industry to take up a position at Cawthron Institute, I thought I knew a few things about the strengths of chemical engineers. We were good at making sense of the available information and, like most engineers; we were good at getting things done. There were no chemical engineers at Cawthron though, no engineers at all at that time. Working alongside biologists, I found that I still had some learning to do.
One learning experience came from a project carried out for BHP NZ Steel. In the early 90s concerns about the threat of invasive marine organisms had led to discussions about controls on ships' ballast water. One proposal was to exchange ballast water in mid-ocean, a difficult and potentially dangerous operation in a 140,000 tonne ship. At the request of New Zealand Steel, Cawthron scientist Lincoln Mackenzie surveyed the sea floor around the iron ore loading terminal at Taharoa, where the ore carriers discharge ballast water. These ships had been doing that for more than 20 years with no apparent problems, so a thorough search demonstrating the absence of any harmful organisms would be useful information for the company. Or at least that was the idea.

Unfortunately for the company, Lincoln found some microscopic objects that he recognised as 'resting cysts': a dormant form which microalgae can adopt when conditions are unsuitable. He was clever enough to find the right conditions for these to hatch. They were identified as Alexandrium ostenfeldii. a toxic algae never before found in New Zealand. In Europe it had a bad reputation as a source of paralytic shellfish poison (PSP), with documented fatalities.

A careful scientist, Lincoln cautioned against jumping to conclusions. We had found nothing in the ballast tanks themselves so, even though the only New Zealand sighting was directly under the ships, we could not yet say it had come in the ballast water. I thought he was being pedantic: to me the cause and effect relationship looked obvious.

The next step was to establish whether these particular cells produced PSP. At that time, the only available test was a bioassay which required several million cells. We had thirteen. At every meeting over the next few weeks I pestered the scientists about progress. The client wanted an urgent answer. I asked Lincoln whether he needed more equipment or extra technician help. Finally, Cawthron's research leader Dr Henry Kaspar became exasperated. "How can I explain so you will understand? Think about babies. They take nine months. They can't be produced in nine days by spending more money or using more people. It's called 'biology'."

I realised that as an engineer I had a basic belief: that anything could be done faster if one tried harder, used more equipment or spent more money. Unfortunately, that often did not apply in Cawthron's work.
Eventually techniques for identifying toxic algae improved. Comparisons of toxin profiles and, some years later, DNA analysis established that there were several different strains of A. ostenfeldii all around the New Zealand coast. They were even found in Jackson's Bay, South Westland, which doesn't see many bulk ore carriers. Not only are they almost certainly not marine invaders, none of those strains has been found anywhere else in the world. So Lincoln was right to be cautious. "So they're endemic?" I asked Lincoln. "We can't say that yet," was his reply, " just that they've only been found in New Zealand".

Intensive larval rearing

I'd left the chemical engineering profession behind when I moved to Cawthron, but occasionally I came across situations or processes that looked familiar. One example, which provided another learning opportunity, was Cawthron's oyster research programme and its larval rearing systems.

The first three or four weeks in the life of a young bivalve are critical. They have a few weeks of freedom as a free-swimming larva, before shedding their swimming organs and settling upon some suitable surface. In oyster hatcheries, the larvae are reared in large tanks in a batch process. Typically a pair of 30 m3 tanks will be used: one containing the larvae at a concentration of around 1 per millilitre; the other clean seawater. Once every 24 hours the larvae are transferred to the fresh tank. The old tank is then scrubbed, sterilised and filled with filtered seawater which is then allowed to "condition".

The process has a yield of about 30% and results in a broad size distribution. "Runts" are discarded during the daily transfer between tanks, which contributes to the low yield. Cawthron scientists had solved the problem of how to grow greenshell mussels in a hatchery and were embarking on an ambitious selective breeding programme. Oysters, which are much easier to grow, were being used to sort out the process before embarking on the real objective. The plan was to grow at least 50 families (offspring from one male and one female) under identical conditions. A large air-conditioned breeding room was built containing one hundred and twenty 130 litre tanks (sixty pairs).

The first trial, with only 20 families, was a nightmare. We had totally underestimated the amount of physical labour required to care for the larvae for three weeks, 24/7. Some hatcheries overseas had been experimenting with continuous systems. It was claimed that these could be run at five or even ten times the larval densities used in a batch system. So began some frantic development work.

It was amazingly successful. The roomful of large tanks became a wall festooned with sixty 1.5 litre soft drink bottles, containing larvae at a density of 100 / ml. Not only was the demand for physical labour reduced significantly, but yield and quality also were markedly improved. Yields were typically more than 90%, while virtually all of the larvae after three weeks were within the top 5% of the size distribution obtained from the batch system. Larval densities of 500 / ml and higher were eventually achieved.

We learned the hard way, however, that things happen very quickly in an intensive system. Whereas in the batch system the larvae would be checked regularly for disease or mortalities, that proved to be inadequate for intensive larval rearing. Success required a great deal of careful observation and knowledge, the ability to recognise when the larvae were unhappy. Once they were ill, it was too late.

This development has been vital for the expansion of Cawthron's shellfish breeding activities, creating massive savings in capital for buildings, plant and equipment as well as operating labour. On the other hand, a large investment in intellectual capital was required.

In November 2012 the government announced its contribution towards a new $23 million facility for the mussel breeding programme. This partnership between Cawthron Institute and the shellfish industry would not have been possible without the development of the intensive larval rearing system. The success of that system has in turn depended upon continued improvements in our knowledge of the behaviour of these organisms during the first few weeks of their life. Once more, engineers had to learn from the biologists.

Final Words

Because I have been out of the industry for so long, I wouldn't attempt to make observations about its current situation and future. I'm certain though that the challenges are even more demanding now, as markets change and the companies adapt. I'm also sure that chemical engineers will still be playing a vital role.
What lessons did I take with me as I left the industry after 21 years? Here are some of them:

- success always involves a lot of hard work
- good people are the key
- humour is important for the health of individuals and the team
- the importance of researchers being connected with users

I absolutely agree with the old Maori proverb, which leaders ignore at their peril:
He aha te mea nui o te ao?
He tangata! He tangata! He tangata!

What is the most important thing in the world?
It is people! It is people! It is people!

Graeme Robertson BE (Chem), Dist. FIPENZ, MRSNZ

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Addendum: Why did I become a chemical engineer?

This question was addressed by several speakers at the symposium held in 1994 to commemorate 50 years of chemical engineering at Canterbury University. Why did we choose chemical engineering? Why not a profession such as lawyer or doctor? We were all highly successful academic learners. We knew that there were other careers which gave more influence, greater earning power and more recognition. An exercise which I went through, initially with some scepticism, during a management course gave me an insight into some of the other reasons why I may have made this choice. The concept had been used by D A Kolb to study learning processes. The participants answered a series of questions designed to evaluate on a two-dimensional grid our individual "preferred learning style". We displayed a preference for either concrete experience or abstract conceptualization, and for either active experimentation or reflective observation. I turned out to be a "converger"; a strong tendency towards the abstract, with a leaning towards the active rather than reflective The exercise was good fun, and gave some useful insights into the characteristics and behaviour of not only the other course participants, but also people back at work with whom I had experienced difficulties. The surprise came when I read the results of a 1969 "Carnegie Commission on Higher Education" survey of representative American colleges and universities. The scores for students of about 40 different disciplines were listed on this same two-dimensional grid (Figure 1).

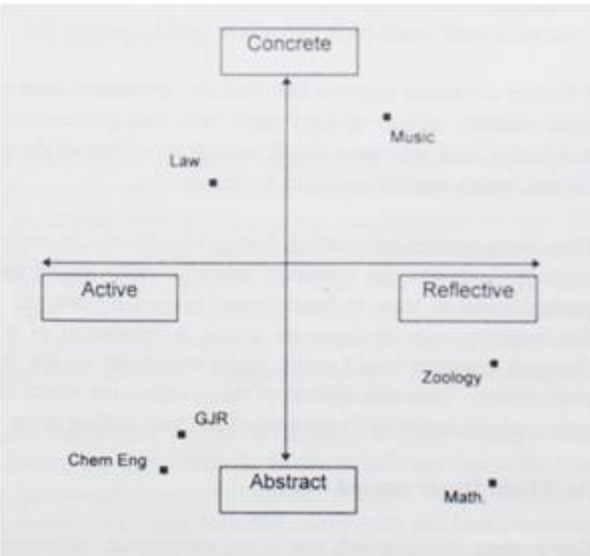

Figure 1: Orientations of academic fields

The engineers all showed up as strong "convergers", strong on abstract thought and tending towards active rather than reflective. My score was right in the centre of this group, close to chemical engineering. Perhaps there was more behind my choice of career than I realised. The fact that I was happy practicing in that discipline for more than 20 years suggested that it had been a good choice. I was fortunate that my first choice of job introduced me to an industry which was to stimulate and challenge me for the next twenty years.

Engineers are a self-selected group, with certain characteristics in common. The Kolb "effective learning style" model also works well in describing individual behaviour within a work situation. Before I start classifying people using this model, I must stress that not only are there differences between individuals, but individuals themselves change with time, or even as they work through a project. I have only felt comfortable with the model when it is used rather loosely, to speculate on a "preferred" mode or style.

A detailed list of the strengths and weaknesses of the various orientations is given in Figure 2. The characteristics of the four quadrants, or preferred orientations, are:

Execution (concrete, active)
setting objectives, committing resources, implementing decisions, "making it happen"
Divergence (concrete, reflective)
good at gathering background information, sensing opportunities, recognising discrepancies in problems, generating alternatives, "identifying"
Assimilation (abstract, reflective)
developing theory or planes, comparing alternatives, defining problems, "explaining"
Convergence (abstract, active)
selecting among alternatives, focusing efforts, evaluating claims, "decision-making"

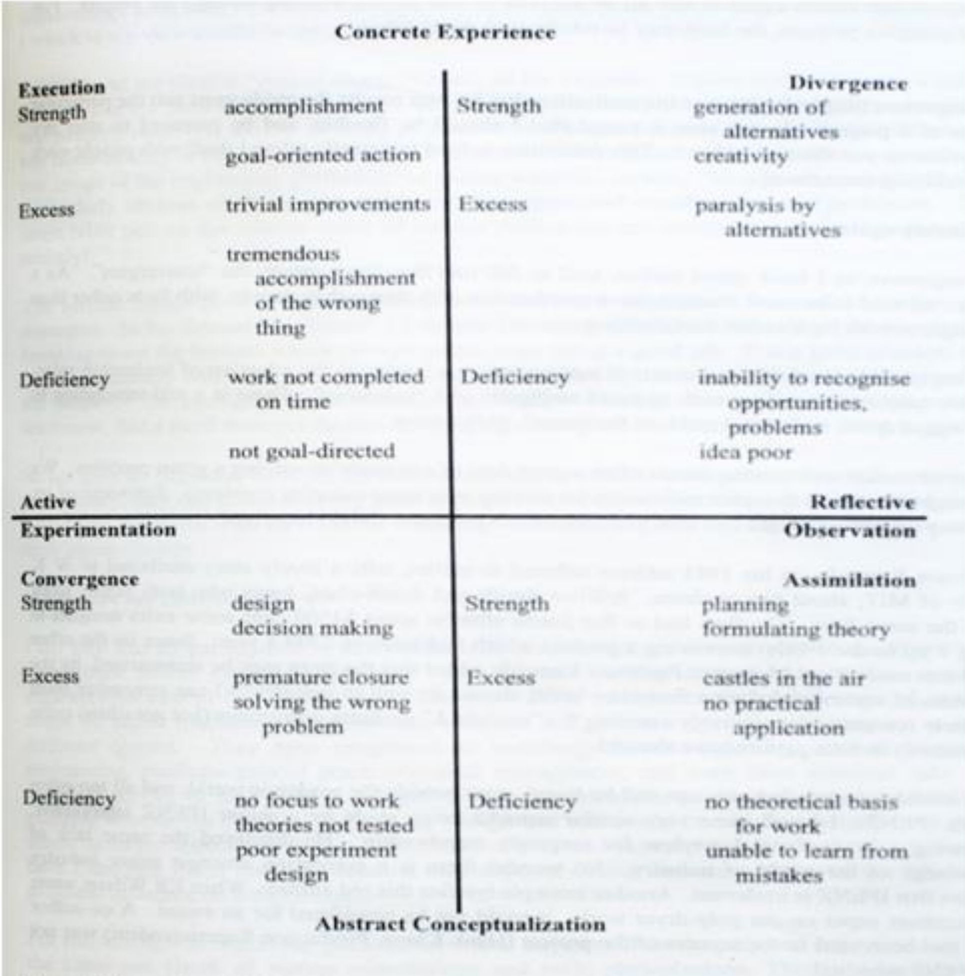

Figure 2: Strengths and Weaknesses
(from Kolb, Rubin & McIntyre, Organizational Psychology, 1984)

It is interesting to consider how the model might apply to a simple project situation. In the initial stages, the identification of opportunities or discrepancies might best be accomplished by someone working in the "divergence" mode. The "assimilator" is then able to develop the theoretical basis for the necessary work, and develop plans. It may be necessary for the next phase to be performed by a person working in the "convergence" mode, to test these plans and theories and solve problems which may arise. "Execution" mode will help to ensure that action is timely and goal-oriented.

These various modes could in fact all be adopted by one person working through the project. For more complex projects, the loop may be run through many times.
An important insight for me was the realisation that for best results the mode must suit the particular phase of a project. In my case it meant that I should be flexible, and be prepared to alter my behaviour to suit the task at hand. This realisation helped me greatly when I dealt with people such as marketing executives!

[1] The interview reminded me of a conversation with one of the engineers, Vince Bidwell, at Lincoln Ventures Ltd. Also back in the 70s, he had been leading a

Agricultural Engineering Institute (AEI) project commissioned by the Liquid Fuels Trust Board to assess the feasibility of producing ethanol in New Zealand from sugar beet. Sometime after the final report had been delivered, he came across a book published in France in the mid-1800s. The majority of the key points in the AEI report could be found in the book!

[2] The bioassay was the “mouse test” which involved injecting a 20g mouse with 5g of neutralised acid extract of the shellfish, then observing it for 24 hours. It's false positive rate of around 30% was the major reason for the almost complete closure of New Zealand's shellfish industry during that first 1992/93 toxic algal bloom. In subsequent years up to $3 million pa was spent on mouse testing. It took about 12 years for Cawthron scientists to develop an alternative test using LC-MS. It is now accepted internationally and Cawthron received an award from the NZ animal ethics committee for a virtual elimination of mouse testing for shellfish.

[3] A summary of my management philosophy during my time as CEO of Cawthron Institute was published in “Boardroom”, the Journal of the New Zealand Institute of Directors, Sep 2005.

[4] Wolfe, D M and Kolb, D A: “ Career Development, Personal Growth and Experiential Learning", in “ Organisational Psychology: Readings on Human Behaviour in Organisations” by D A Kolb, I M Rubin and J M McIntyre, Prentice Hall 1984 ISBN 0-13-641290-4