TECHNOLOGICAL LEARNING: TOWARDS AN INTEGRATED MODEL

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ABSTRACT

The acquisition and growth of technological knowledge is fundamental to competitive advantage in the emerging knowledge economy. This article explores the notion of technological learning as a means of developing the capabilities that underpin long term sustainable innovation. The research project was designed to identify new ways of understanding learning in the context of technology-driven SMEs, so the methods employed were essentially inductive in nature. This has resulted in the development of a comprehensive framework comprising four inter-related knowledge categories (Identity, Direction, Capability, and Relationship), each of which has an associated learning process (learning by reflecting, learning by strategising, learning by doing, and learning by interacting). We argue that it is the interaction between these knowledge categories that generates the new insights that are essential to technological learning.

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1. BACKGROUND

The term 'technological learning' is gradually gaining currency amongst writers who are interested in the development of technology-driven industries and firms. For instance, Dodgson (1991) details the learning characteristics of a leading European biotechnology company; Kim (1997) explores both macro and micro levels of analysis to explain the dynamics of learning in several of Korea's highly successful technology-based industries; and Carayannis (2000) identifies learning practices employed by US and European companies that have demonstrated long term success and prosperity in a variety of technology-driven industries. In parallel with these major works, there is also an increasing number of journal articles that focus on learning in high-tech or technology-driven industries (eg Bohn, 1994; Ernst, 1998; Hitt, Ireland, & Lee, 2000; Hobday, 1994; Kazanjian, Drazin, & Glynn, 2000; Zahra, Ireland, & Hitt, 2000).

It is no surprise that the emergence of this interest in technological learning coincides with growing global awareness of the knowledge revolution and its implications for business. Increasing numbers of scholars are now seeing knowledge, rather than physical assets, as the ultimate source of competitive advantage and long term sustainability (eg Barney, 1991; Conner & Prahalad, 1996; Grant, 1996; Sanchez & Heene, 1997). From this strategic perspective, the pace of technological change, and the discontinuities that new technologies bring, present not only significant threats to conventional business practices, but also, a multiplicity of new opportunities for innovation. This new competitive landscape demands new strategic concepts and even new language. For instance, the established language of 'technology transfer' and 'technology diffusion' is built upon assumptions of linearity and determinism (Rothwell & Zegveld, 1985) that are of questionable value in dealing with the complexities of contemporary knowledge-based business. By contrast, 'technological learning' implies an ongoing and interactive process that is potentially more able to accommodate the unpredictable, emergent qualities of innovation and new knowledge production.

Whenever new language is introduced to a field of study, a period of definitional clarification necessarily ensues. In the case of 'technological learning', despite differences in detail, there seems to be wide acceptance amongst writers that it refers to the process by means of which technological knowledge is gained. For instance, Dodgson (1991:110) defines technological learning as "the ways firms build and supplement their knowledge-bases about technologies, products and processes, and develop and improve the use of the broad skills of their workforces". Kim (1997:6) uses technological learning simply "to depict the dynamic process of acquiring technological capability." And Hitt et al (2000:235) suggest that "technological learning is linked to the firm's ability to develop, maintain and exploit dynamic core competencies". Empirical studies of technological learning have, however, almost invariably focussed upon knowledge or 'learning' as a noun (ie the outcomes of learning), rather than the learning process itself. Indeed there is a real paucity of research into how technological knowledge is created, maintained, and disseminated in technology-driven settings.

In this article, we endeavour to address this imbalance in the literature by explicitly examining technological learning as a process. We concur with Kazanjian et al (2000) who see technological learning as a specific instance of organisational learning. Accordingly, we attempt to identify linkages between these two related fields of research. Our study, which is essentially inductive in its design, has unfolded in two stages, beginning with a broad spectrum, multi-case exploration of technological knowledge and learning practices, and followed by the very detailed mapping of the learning processes associated with specific innovations. The latter stage of fieldwork is still in progress as we write, but the results reported here are already well grounded in our empirical data. The flow of the article is consistent with an inductive approach in that we begin by outlining the methodological details of the study; then we present our results; and finally we compare these findings with the broader literature on organisational learning.

2. DESCRIBING THE STUDY

The focus of this research was to discover the technological learning processes by means of which technology-driven companies acquire and sustain the knowledge that shapes their ongoing competitive advantage. Because the word 'technology' is used in many different ways, we began by developing a working definition to inform our research design. Ultimately we opted for a broadly inclusive definition, as follows:

> *Technology comprises the tools and concepts used to convert resources (inputs) into high value-added products and services (outputs).*

The technologies that we considered for inclusion in this study, therefore, could be either 'hard' or 'soft', and either primary or secondary in the production process.

The companies that participated in the research were all small and medium-sized enterprises (SMEs) within the manufacturing sector. More precisely, all the participating firms employed between 20 and 100 staff. This size constraint was imposed on the sample because SMEs are widely regarded as the engines of economic growth, being the most prolific creators of innovations and jobs in most economies, especially those that are embracing the knowledge revolution. Our assumption was, therefore, that examples of technological learning would be more in evidence amongst SMEs as compared with larger manufacturing companies. To further strengthen this assumption, we selected only companies that were regarded as active technological learners by their industry peers.

We struck a balance between diversity of sources and inter-case comparability by limiting the selection of case companies to three industries. Each of these industries has distinct characteristics that were discernible in the specific context of this study. The first was the plastics industry, which is characterised by manufacturing technologies such as injection moulding, blow moulding, rotational moulding and extrusion. These technologies, although generally quite sophisticated, are mostly readily available off the shelf. Consequently innovation in this sector usually relates to new uses of plastics materials, or creative new product designs, although some of the case data that we present later also demonstrates innovative process development in the plastics industry. Secondly, we selected light engineering companies that were involved in a variety of industries, including marine construction, agricultural products, and transportation. Innovation in this industry is often the combination of ingenious process inventions and clever product design, supported by the development and implementation of modern information systems. The third industry that we chose was food processing where the manufacturing technologies tend to be relatively simple, but sophisticated science often underpins new product design and development.

The goal of our study was to build new understandings that were grounded in our field observations, rather than to test extant theory. Consequently we opted for a research design that would produce rich data capable of providing new insights into the process of technological learning. We used semi-structured interviews, analyses of relevant documents, and on-site observations to build our understanding of the context within which each participating company was operating. More targeted interviews then focussed on critical incidents where interviewees were asked about particular innovation events in which they had been personally involved. These interviews probed into the nature of the innovation, how it evolved over time, who else was involved and in what capacity, and what drivers had motivated the innovation process.

The first stage of the study was designed to identify the knowledge types and learning practices found in technology-driven firms (Simpson et al., 2000). The research involved in-depth interviews in 12 case companies (4 in each of plastics, light engineering and food processing). We guaranteed confidentiality to all the participating companies, so their identities have been disguised in all reporting of our results. Each case study had a member of the research team assigned as the case leader, although we often worked in pairs to conduct interviews. We interviewed the CEO, general manager, owner or other senior manager of each case company, plus other managers, co-owners, and technical staff as available and appropriate for the setting. All interviews were tape recorded and verbatim written transcripts were prepared.

The initial analysis of each case was undertaken by the case leader, who coded the transcripts into thematic categories as perceived by the analyst. No predetermined codes were used. These themes were then shared with the other members of the research team, each of whom brought their own themed case studies. This process provided an opportunity for comparisons between cases and the identification of common themes. By an iterative process, moving between our field observations and the emerging knowledge framework, we were able to classify all of these themes into four overarching knowledge categories, which we have named Identity, Direction, Capability, and Relationship (IDCR). The details of these knowledge categories and their associated learning practices are set out in the next section of this article.

Having established a working framework of technological knowledge, the second stage of this study was designed to take a longitudinal perspective in order to map the learning processes associated with particular innovations. Data were collected as identified innovations evolved, using multiple, largely unstructured interviews, as well as on-site researcher observations. The data collected were necessarily very rich and highly complex, as we endeavoured to map all of the phenomena that were interacting during the process. We used rich pictures to capture this complexity. These were developed over time by the researchers and informants together. As mentioned earlier, this stage of the study is still in process.

3. WHAT WE FOUND

3.1 Stage One - Four Knowledge Categories

The 12 case studies that we undertook in the first stage of this research provided in-depth information on both the knowledge and learning processes that characterise technology-driven SMEs in the manufacturing sector. There were clear differences between the three industries that we included in the study, related largely to the different types and degrees of complexity of the technologies employed. For instance, the case companies in the food processing industry tended to seek technological advantage through the use of secondary, management or information technologies rather than advances in their actual production processes. By contrast, the light engineering industry cases typically focussed their attention on improving the technologies used directly in production.

Nevertheless, all four of the following distinct, but inter-related categories of knowledge (IDCR) were identifiable in every one of the case studies.

Identity

The sense of identity reflected by an organisation and the individuals within it is what shapes the beliefs and assumptions that guide learning. Identity in small businesses is very much influenced by the history and qualities of their leadership. For instance in one of our case companies the founder and owner is described by his partner as

> "a genius, very technically innovative, very creative, he has a huge knowledge and experience of a range of engineering, scientific and practical things … [and] he comes from a farming background so, as well as his engineering degree he has got all of that practical thinking."

Describing his own learning style he says:

> "I am always searching the boundaries. Legal and Accounting minds don't grapple with this so well. I have talked with some friends and they find my way of thinking always a bit on the edge, always searching the boundaries. They find it difficult to grapple with."

This eccentricity in style and approach is apparent throughout the company, even to the extent of the physical space in which it operates. The factory is quirkily designed and painted a very distinctive purple colour, making it quite a landmark in the rural town where it is located. In this way, the company cultivates an external image of being different and special.

In fact, each industry that we studied had its own unique identity:

> "Marine companies draw people for emotional reasons … because they like boats … [this] is a company that seems to breed a lot of emotional people, we have a lot of people who work very very hard. It's great, and the owners have that sort of dedication [too]"

Another illustration of the influence of Identity comes from a company that has been in family ownership for three generations. Family values permeate every aspect of this company's activities including the management team:

> "There's eight of us that sit around this table every morning….we have our cup of tea, our morning tea, and…it is not a formal meeting … I've got the team now to the stage that they feel as though we are all one big family."

winning new overseas customers:

> "….he liked the way we'd gone about it, and then I said to him, "Well the next thing we should do is, we should get you out. You should come and have a look at us. Look at our business, meet the family""

and finding new equity partners to allow for business expansion:

> "we saw the opportunity only being successful for us if we had a good family partnership … I felt very confident and so did [the other partner] that the two families could work together … we were both quite happy to have a 50/50 split. Some people stand back and say "come on this is a bit strange that you've got exactly 50/50 - does it work?" Well it does work … [but] it requires the right sort of people to make that sort of thing happen"

The development of Identity requires a level of self-knowledge that comes from the practice of 'learning by reflection'. Knowing more about Identity, whether it be at an individual or collective level, requires the skills and willingness to look within and to learn from experience. Several of our case companies gained knowledge about themselves though crisis situations that threatened their very existence.

> "We gradually moved our production offshore but unfortunately, I was saddled with the great big building next door with a rent flow, and I was locked into a lease … The business made a lot of losses … so I had to put out my hand and go to the bank. The bank said "Oh yes, we'll support you through this - we can see your problems and you've been working hard and you've done this and that's all looking good - yes, we'll support you through this thing". Then they put in a receiver overnight."

The subsequent survival of this company demanded very rapid learning by reflection in order to overcome the heightened difficulties that they faced.

Direction

Knowing yourself is an important aspect of learning, but so too is knowing where you are headed. This category includes knowledge of the environmental context, resource management procedures, and effective planning. The SMEs in our study invariably adopted quite informal strategic processes, allowing them the flexibility to respond rapidly to changing circumstances.

> "We decided we wouldn't build another machine five months ago because we could keep things going at that level and then two months later, we've totally changed. We're putting a huge push into building another machine because the sales are increasing tremendously, the markets are broadening. We've sold some to Japan and then we're looking at [other] world markets. So, things like that mean that we need to change. And the fact that we have the ability to manufacture our own machines and technology is a real advantage. Because we can make that decision and we can change direction."

Having a clear vision of the company's long term direction is a key component of this knowledge category:

> "I want to keep growing substantially I suppose. I mean at the moment we're struggling, we will get to $10 million, probably get to $12 million [annual turnover] next year. I would like to think in 5 years time it might be $25 million. And I see that growth coming through as well as through new developments from engineering, I see it coming through acquisition as well. We should probably look at buying other companies that are within the market … We can grow a lot by taking share off our competitors [too]."

And having the necessary skills and resources to scan and interpret the environment is another essential contributor:

> "We think we know which way we are going but one thing that is lacking is really good fundamental marketing information. I suppose that's the reason for [an engineer] to go on a trip because he can talk to the engineers who serve our customers and separate out all the marketing hype, the sales hype … when we get his report back from that, we're going to develop what we are going to do and as a team agree on where we are going and then start putting a few goals in place."

as is having appropriate controls in place to ensure that the desired Direction is sustained:

> "we've got the [product] deal - we've taken a risk, we've taken a position on that, we've spent a lot of money, but we still have to sit here and say now what if that guy doesn't come through with the orders? What if he's not happy with the testing? That's gonna delay projected sales on that thing for anything up to six months. How are we gonna cope with that? Because I don't want to get to the end of the Financial Year and say "well that was a bad one"."

A team approach to the formulation of plans and setting of goals is always evident in our case companies:

> "We meet, we have what we call a "development list" which is all the ideas that the sales guys have collected and opportunities that they've collected out in the market place. And we will then list those and control them and work on the projects and try and bring them to fruition. So that development meeting really is just a forum for us to, to sit down and, we've got so many things on-the-go that we just go through this basically great big list of all the different projects and make sure they're on track and you know, sometimes it's a bit of a chaos type affair"

We have adopted the term 'learning by strategising' to describe the process that underpins the development of Direction knowledge. This involves the skills of strategic thinking, environmental scanning, interpretation and planning, where these skills not only reside within individuals, but are also widely shared through team processing within the companies.

<u>Capability</u>

Technical knowledge, and the ability to apply it in increasingly complex settings, is fundamental to technological learning. There are basic requirements in any industry:

> "You need to have a thorough understanding of Physics and Chemistry, and engineering … It does guide you in the right direction…does eliminate a lot of mistakes."

Or conversely:

> "University qualified is fine so long as they are real world people. Sometimes you get the wafflers and that is not it. That is a terrible generic statement to make. We look for people who can do a job and we are very lucky with the talents we have got around the place. On the floor some of them are qualified and some of them are just what you call qualified by experience"

But also, the breadth of perspective that comes from multiskilling is crucial for innovation.

> "I don't want a guy to come in with just one way it's got to be done. You've got to see 20 ways, options. And you work through all those 10 or 20 ways, and some of them might seem stupid at the time but maybe little elements out of those make sense"

Capability is not just about the skills of individuals though. It also incorporates the ways in which knowledge is captured by the company. Manufacturing and management systems are a crucial component of this organisational level of knowledge.

> "When I first came in, every job was like starting from scratch again. So, we hadn't learnt anything from the last time we did it … [now] we have got extremely good systems in place, we have full MRP and … we've got the bill of materials … we have the routings for the factory, and we have all work instruction that pops out whenever we get a new order in. And, OK….we've forgotten how we did it last time but it's all documented now - we go back through, we have all the examples - we are trying to get to the stage now where the next step is … we've just bought a digital camera so that we can photograph things so that becomes part of the printout package as well. And, it really doesn't matter that we haven't done it for 12 months ... we can go back, and within a couple of shots reproduce some good quality."

Experiential learning, or 'learning by doing', is the process that develops Capability knowledge.

> "the thing is, the excitement to me, is ... I'm …when the fitters are doing things, I go there at the crucial times. It might merely be two minutes a day to see the crucial thing they are doing. It might be the way a rod tumbles out of the thing or the way a little mechanism goes. And I've got to be there that crucial time that I get my hands dirty with the fitters and we fiddle around with this thing and we talk about it, and then we make decisions."

Relationship

Relationships are essential for learning to occur in technology-driven firms, and this is especially true of small companies where individual personalities may easily dominate the organisational environment. Relationships with customers were at the forefront of concern amongst our case companies:

> “we take a lot of pride in treating the customers well, we’ll do anything to make sure we have a happy customer”

Explaining why his company sought ISO9001 certification, one CEO said:

> “We did that about 3 years ago. I felt that if we are going to go into large companies [overseas], even with our existing customers, we had to give them every reason to stay with us, and not to move away. And, you know, it’s very fair to say that we’ve had customers over there for a number of years and we are competing head on with worldwide suppliers, into that market, and, we had to have all the bases covered. It’s one thing to have the product, one thing to have the price….but you really can’t give your customer any excuse whatsoever to move away.”

External relationships with customers, suppliers and so on are important, but so too are internal relationships within the company.

> “We have a mixture of all sorts of talents. My job really is to get all those challenges together. Sometimes it’s like trying to mix oil with water, but we’re not doing too badly. I mean we sit here and have a few disagreements but that is fine, that is cool ... the guys want the same thing which is for [the company] to continue to grow, and that is really special.”

Relationship knowledge is not just about whom you have relationships with, it is also about how you communicate:

> “I’ve had to change a lot because when I was in the [old business] you could be more autocratic. You could be an individual and you came up with your own ideas. That’s how you saw it, that’s how you built it and that’s how you presented it. In this business, you come up with some ideas and you throw them on the table, and all the rough edges get knocked off by the team.”

and the trust that is built:

> “I’ll give an example of this real business ... we are working with [an overseas customer]. That has been done not even on a handshake but just on a meeting sitting around the table.”

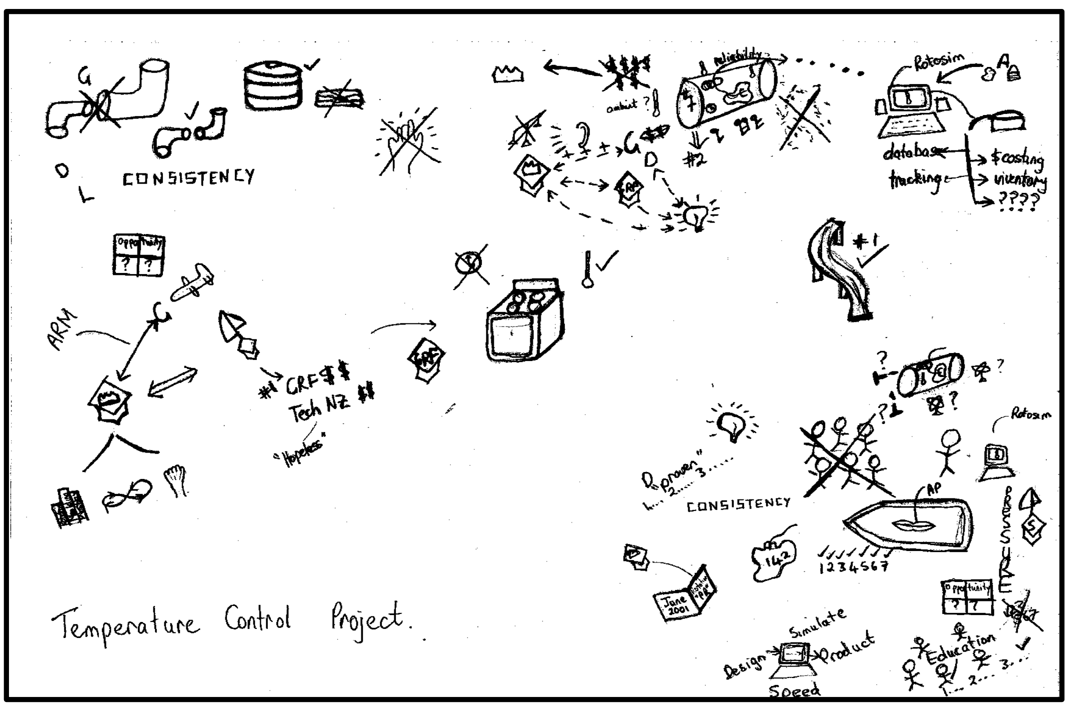
Building Relationship knowledge involves a process of ‘learning by interacting’. It is through our interactions with others both within an organisation and in the wider community that we construct our networks of relationships.

3.2 Stage Two - Mapping a Learning Process

Drawing on materials from the second stage of our data collection, we have selected one particular instance of an innovation process as an illustrative example of the longitudinal acquisition of technological knowledge. The company that generated this innovation is in the plastics industry. In fact it is the second largest supplier of plastic playground componentry to a global fast food chain, which in turn, is the largest playground operator in the world. These colourful and creative playground components are manufactured using rotational moulding, a plastics processing method for producing large hollow parts.

The innovation that we have chosen to discuss here, which is one of many that we might have chosen from this company alone, relates to the ovens used to control the plastic moulding process. Figure 1 is a rich picture that we developed with the various actors through a series of interviews. Although we anticipate that readers may be overwhelmed by the level of detail in this picture, we nevertheless felt that its inclusion was important to demonstrate the extreme complexity of this innovation process. Much of this complexity is necessarily lost in any written, and linear, account. What follows is one such linear description of the content of this picture, in which we have highlighted the various categories of knowledge as they appear.

Figure 1: Rich Picture of the Temperature Process Control innovation



One of the challenges facing the company (DIRECTION) was to reduce "the problem of fit-ups", that is moulded components that do not fit together as they should. This problem arises because of variations that occur in the rotational moulding process, and it becomes a significant issue when playground components are shipped at different times to markets all over the world. Some years earlier, Herb, the CEO, had met Sid, a Professor of Engineering, at an international conference on rotational moulding (RELATIONSHIP). As chance would have it, Sid subsequently took up a position at a University located in the same city as Herb's company. Sid spent the first year of this new appointment "going around small [plastics] companies … trying to tease out from them what [the University] could do for them". During this period, Sid and Herb became reacquainted (RELATIONSHIP).

When the problem of fit-ups surfaced, Herb talked it over with Sid who said that "the obvious thing to do is to try to implement some process control". He suggested that a temperature-controlled process (CAPABILITY) would eliminate some of the inconsistencies in the moulded products. Although temperature monitoring systems were available already, this off-the-shelf technology was too expensive, did not incorporate automated controls, and was incapable of operating in a factory environment. Herb, an entrepreneur who "doesn't stand there and let things happen" (IDENTITY), realised this was one way the industry would be moving in the future (DIRECTION), and "instead of being left behind" (IDENTITY) he felt the company "should be able to do it and do it better" than the proprietary systems already available (CAPABILITY).

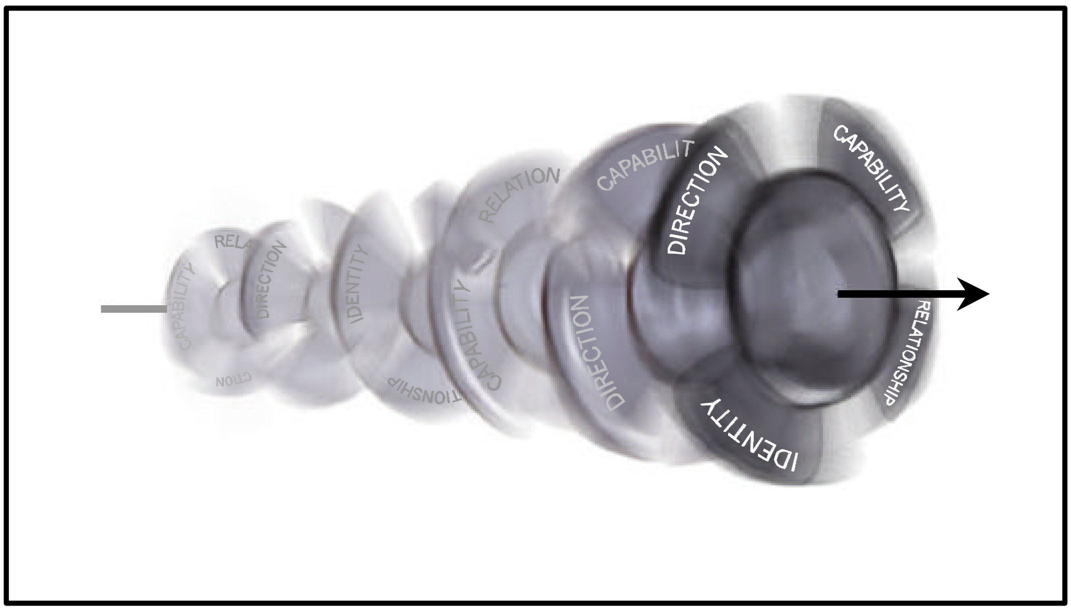
Stan, a research student from the University (RELATIONSHIP, CAPABILITY), was brought on board to develop the necessary process control systems. Over a one-year period, he worked closely with Ernie (RELATIONSHIP), the production manager, to find a practical and reliable means of using temperature to control the rotational moulding process. From Ernie's perspective "practical day-to-day reliability" was essential when running a plant (CAPABILITY); deadlines had to be met (DIRECTION) and a new process that "crashes every two months is no good". He wanted a process that was not only reliable, but also able to be managed by staff on the plant floor (CAPABILITY). After a great deal of trial and error, Ernie was able to report that the project "has been worthwhile, and we will have a far better product" (IDENTITY).

This innovation is the first practical and reliable rotational moulding temperature control system to be developed and implemented at factory level anywhere in the world. At every stage during this ground-breaking technological development Herb has been prepared to "put his money where his mouth is" (DIRECTION). Furthermore he has been unstinting in his support of the people working on the project (RELATIONSHIP). The culture of the company is characterised by the catch phrase "there isn't anything you can't do with plastic". From the shop floor through to management, the company embraces change, provided it leads to an improvement in the product (IDENTITY).

One consequence of implementing this temperature-controlled process is that the company now has access to a whole raft of new process data. The computer system developed to facilitate the temperature process produces a variety of outputs as a by-product of the "cooking" process. This then raises a number of new opportunities (DIRECTION). For instance, the computer-generated records will provide assistance with the inventory system (CAPABILITY), much-welcomed by the accounting department. Exactly how many new opportunities will arise from this innovation has yet to be explored by the company (DIRECTION).

This mapping of an innovation shows clearly how the different categories of knowledge (IDCR) are woven together throughout the process. Furthermore, the final paragraph of the description hints at the generative nature of this interweaving, as new knowledge progressively emerges. Over time then, each knowledge category grows. We have endeavoured to represent the dynamic nature of this technological learning process in Figure 2. The horizontal axis in this figure represents the passage of time. Spinning around this axis is a four-bladed propeller, each blade representing one of the four knowledge categories. We envisage this spinning propeller somewhat like the colour wheels that are familiar to anyone who has studied science at school. When the wheel is static we can see that its surface is coloured in wedges representing all the colours of the rainbow. When the wheel spins, however, these colours combine, giving an overall impression of whiteness. In the same way, when our knowledge propeller is static, we can discern the different categories (colours) of knowledge. When it spins, the knowledge categories interact giving an holistic (white) impression of the technological learning process.

Figure 2: The Technological Learning Process



The time dimension in our conceptual model reflects the progressive acquisition of new knowledge. As the propeller spins, it moves forward along this time axis, and at the same time, it becomes bigger. Not only does each blade of the propeller increase in size, but so also does the hub, which is where the various categories of knowledge interact. Thus the potential for complex interaction between knowledge categories becomes progressively greater over time. This concept of net growth in knowledge is consistent with the theory of increasing economic returns (Arthur, 1996), which suggests that any competitive advantage based on superior knowledge will be magnified in the marketplace, leading to an even greater knowledge advantage.

Exploring the metaphor further, we can see that the stability of this spinning propeller is dependent upon a balance between all four knowledge categories. We argue that the long term sustainability of the innovation process is dependent upon achieving a balanced approach to technological learning. If one blade of the propeller were to grow more or less quickly than the others, the system would become unbalanced and would ultimately self-destruct. Sadly, much of the literature to date on technological knowledge development focuses exclusively on the acquisition and management of technical capability. The model that we are proposing here, takes a much broader view of the types of knowledge that interact to facilitate effective technological learning.

4. DISCUSSION

To recap, our empirical observations have led us to conclude that there are four distinct categories of knowledge that dynamically work together to generate long term sustainable innovation. The totality of these categories of knowledge and their interactions, which become increasingly complex over time, provides a comprehensive framework for understanding the process of technological learning. The four knowledge categories are Identity, which represents self-perception at individual and cultural levels, Direction, which incorporates strategic considerations, Capability, which refers to technical knowledge, skills, and related organisational systems, and Relationship, which conveys the inter-personal dimension. Further, each of these categories has a specific learning process by means of which that type of knowledge is accumulated. These are respectively, learning by reflecting, learning by strategising, learning by doing, and learning by interacting.

Within the field of Organisation Studies, there are already substantial bodies of literature dealing with each of these categories of knowledge. However, these tend to stand alone as discrete entities, whereas our emphasis is on the interactions between them, and in particular the generative potential of these interactions. It is in this context that the Organisational Learning literature offers valuable insights. The rapid ascendancy of this area of inquiry over the past decade or so is evidenced by a number of comprehensive reviews (Easterby-Smith, 1997; Fiol & Lyles, 1985; Hedberg, 1981; Huber, 1991; Levitt & March, 1988; Shrivastava, 1983). The learning models that have proven to be most resilient fall into two categories. Firstly, those that draw on the experiential learning tradition, make explicit the link between action and learning (eg Argyris & Schön, 1978; Bateson, 1972; Kolb, 1984). From this perspective, the development of knowledge is based on empiricist assumptions. Secondly, those that recognise the socially constructed nature of knowledge, focus their attention on the social context in which learning occurs (eg Brown & Duguid, 1991; Cook & Yanow, 1993; Lave & Wenger, 1991). These writers reject the tenets of positivism, and rather than aiming to develop objective theory that generalises causality, they seek more modestly to facilitate awareness of the learning process amongst organisational players.

Arising out of these largely complementary approaches, two key dimensions of organisational learning may be identified (eg Spender, 1996). The first of these is the Individual – Collective dimension, which acknowledges that although learning is a cognitive function of the individual mind, this process both shapes, and is shaped by, the assumptions and beliefs that are shared collectively within a community. In this context, community may refer to a variety of entities including work groups or teams, non-work social contacts, organisations, and / or the wider society. Shared understandings within such communities result from the complex interactions between individual members. The organisational boundary does not have a privileged position on this dimension. Seeing the dimension as a continuum reminds us that research into organisational learning needs to be framed systemically, rather than by the more conventional, and positivist, separation by level of analysis.

In our model, each of the four knowledge categories explicitly accommodates the individual as well as the environment(s) within which she or he learns. So, for instance, Identity is not just about the qualities and attributes of the individual, which is often the sole focus of the Entrepreneurship literature, but it also includes the cultural elements of an organisation's identity. The process of strategising by means of which Direction knowledge is developed, involves not only the visionary leader or the team that formulates and implements plans, but also the influence of the strategic environment. Capability captures not only the technical knowledge and skills of individuals, but also how these skills are combined to generate company level knowledge that ultimately resides within organisational routines and systems. And finally, Relationship is about the interpersonal engagement of individuals with themselves, each other and their communities. Each of the knowledge categories may, therefore, be viewed as a technological learning sub-system that encompasses the entire Individual – Collective dimension.

The second key dimension of organisational learning is the Tacit – Explicit dimension, the origin of which is generally traced to Polanyi (1962) who argued that learning involves the exchange of knowledge between explicit and tacit forms. Explicit knowledge is that which is codifiable, able to be expressed in words, and which therefore has a sense of precision and purity about it. Tacit knowledge, by comparison, is a richer and murkier pond because it reaches beyond conscious knowledge into the psychological realms of the subconscious. Whereas explicit knowledge may be gained by intellectual processes, tacit knowledge is derived primarily from the experience of being deeply immersed in the phenomenon of interest. It is this immersion that gives rise to the insights that ultimately lead to new learning.

Our model is inclusive of both explicit and tacit forms of knowledge. The four knowledge categories themselves do not differentiate between explicit and tacit knowledge, both of which occur in each category. In fact, these categories could not grow and learning could not occur if either form of knowledge was excluded. In addition, the learning processes attached to each knowledge category reflect the role of different types of activity in the growth of tacit knowledge. In an organisational setting, in particular when innovation processes are evolving, there is an abundance of opportunity to learn individually and collectively through immersion in a variety of activities and experiences.

Thus the two key dimensions frequently used by Organisation Learning scholars are also incorporated in our model of technological learning. Hitt et al. (2000), Lam (2000), and Spender (1996) have all used these key dimensions to define typologies of organisational knowledge. However, there is no basis for direct comparison between these typologies and our knowledge categories, which have been induced from observation rather than deduced from theory. More importantly, since our interest is in process more than content, it is necessary to go beyond static typologies. Nonaka & Takeuchi (1995) and Crossan, Lane, & White (1999) have both reported process-based models of organisational learning that reflect the dynamic evolution of knowledge through learning. Nonaka & Takeuchi describe organisational learning unfolding as a relatively orderly succession of the processes of Socialisation, Externalisation, Combination, Internalisation, Socialisation, and so on, whereas Crossan et al acknowledge that the four subprocesses in their model, namely Intuiting, Interpreting, Integrating and Institutionalising, are not necessarily inter-related in an orderly manner.

These two models of organisational learning (Nonaka & Takeuchi, 1995; Crossan et al., 1999) are a useful adjunct to our framework for technological learning in that they describe how any one of our knowledge categories might grow over time. However, the specific contribution that we have made is to acknowledge the generative interaction between different types of knowledge (IDCR) in the dynamic process of technological learning. It is this process, with all its subtleties and complexities, that underpins sustainable innovation. For technology-driven companies, and especially SMEs, that are struggling to come to terms with the demands of the emerging knowledge age, our model aims to raise awareness of the learning processes involved in creating long term competitive advantage through innovative technology.

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REFERENCES

Argyris, C., & Schön, D. (1978). *Organizational learning: A theory of action perspective*. Reading, Massachusetts: Addison Wesley.

Arthur, W. B. (1996). 'Increasing returns and the New World of Business.' *Harvard Business Review, 74*(4), 100-109.

Barney, J. (1991). 'Firm resources and sustained competitive advantage.' *Journal of Management, 17*(1), 99-120.

Bateson, G. (1972). *Steps to an ecology of mind*. New York: Ballantine Books.

Bohn, R. E. (1994). 'Measuring and managing technological knowledge.' *Sloan Management Review, 36*(1), 61-73.

Brown, J. S., & Duguid, P. (1991). 'Organizational learning and communities-of-practice: Toward a unified view of working, learning and innovation.' *Organization Science, 2*(1), 40-57.

Carayannis, E. (2000). *Strategic management of technological learning*: Lewis Publishers.

Conner, K. R., & Prahalad, C. K. (1996). 'A resource-based theory of the firm: Knowledge versus opportunism.' *Organization Science, 7*(5), 477-501.

Cook, S. D. N., & Yanow, D. (1993). 'Culture and organizational learning.' *Journal of Management Inquiry, 2*(4), 373-390.

Crossan, M. M., Lane, H. W., & White, R. E. (1999). 'An organizational learning framework: From intuition to institution.' *Academy of Management Review, 24*(3), 522-537.

Dodgson, M. (1991). *The management of technological learning: Lessons from a biotechnology company.* Berlin: Walter de Gruyter.

Easterby-Smith, M. (1997). 'Disciplines of organizational learning: Contributions and critiques.' *Human Relations, 50*(9), 1085-1113.

Ernst, D. (1998). 'Catching-up, crisis, and industrial upgrading: Evolutionary aspects of technological learning in Korea's electronics industry.' *Asia Pacific Journal of Management, 15*(2), 247-283.

Fiol, C. M., & Lyles, M. A. (1985). 'Organizational Learning.' *Academy of Management Review, 10*(4), 803-813.

Grant, R. M. (1996). 'Toward a knowledge-based theory of the firm.' *Strategic Management Journal, 17*, 109-122.

Hedberg, B. (1981). 'How organizations learn and unlearn.' In P. C. Nystrom & W. H. Starbuck (Eds.), *Handbook of organizational design* (pp. 3-27). Oxford New York: Oxford University Press.

Hitt, M. A., Ireland, R. D., & Lee, H.-u. (2000). 'Technological learning, knowledge management, firm growth and performance: an introductory essay.' *Journal of Engineering and Technology Management, 17*(3-4), 231-246.

Hobday, M. (1994). 'Technological learning in Singapore: a test case of leapfrogging.' *Journal of Development Studies, 30*(4), 831-858.

Huber, G. (1991). 'Organizational learning: The contributing processes and the literatures.' *Organization Science, 2*(1), 88-115.

Kazanjian, R. K., Drazin, R., & Glynn, M. A. (2000). 'Creativity and technological learning: the roles of organization architecture and crisis in large-scale projects.' *Journal of Engineering and Technology Management, 17*, 273-298.

Kim, L. (1997). *Imitation to innovation: The dynamics of Korea's technological learning*. Boston, MA: Harvard Business School Press.

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Englewood Cliffs, NJ: Prentice Hall.

Lam, A. (2000). 'Tacit knowledge, organizational learning and societal institutions: An integrated framework.' *Organization Studies, 21*(3), 487-513.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Levitt, B., & March, J. (1988). 'Organizational learning.' *Annual Review of Sociology, 14*, 319-340.

Nonaka, I., & Takeuchi, H. (1995). *The knowledge creating company*. Oxford: Oxford University Press.

Polanyi, M. (1962). *Personal knowledge: Towards a post-critical philosophy*. London: Routledge and Kegan Paul.

Rothwell, R., & Zegveld, W. (1985). *Reindustrialization and technology*. Essex: Longman Group Ltd.

Sanchez, R., & Heene, A. (1997). 'Reinventing strategic management: New theory and practice for competence-based competition.' *European Management Journal, 15*(3), 303-317.

Shrivastava, P. (1983). 'A typology of organizational learning systems.' *Journal of Management Studies, 20*(1), 7-28.

Simpson, B., McGregor, J., Seidel, R., Kolb, D., Henley-King, J., & Tweed, D. (2000). 'Learning in the manufacturing sector.' *University of Auckland Business Review, 2*(1), 38-50.

Spender, J. C. (1996). 'Making knowledge the basis of a dynamic theory of the firm.' *Strategic Management Journal, 17*(Winter Special Issue), 45-62.

Zahra, S. A., Ireland, R. D., & Hitt, M. A. (2000). 'International expansion by new venture firms: International diversity, mode of market entry, technological learning, and performance.' *Academy of Management Journal, 43*(5), 925-950.