The functionality grid as paradigm for Management of Technology

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DECLARATION

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F.C. Lochner 2011

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ABSTRACT

Technology is a critical component in modern society. Management of Technology (MOT) should be a major focus of management studies. At present the status of MOT is much less than it should be. Part of the reason is that there is little consensus about the body of knowledge for MOT. This can be traced down to as far as an inadequate consensus about the very nature of technology itself. There is a need for a simple and elegant conceptual foundation. There is a need for an accepted paradigm to govern MOT.

The paradigm discourse initiated by Thomas Kuhn allows for a comprehensive frame of reference about theory contestation and about the attributes required from a contesting theory to achieve the ultimate status of a paradigm. In order to help create a coherent and streamlined conceptual foundation for MOT, this research evaluates the functionality grid as a paradigm. To realise this goal, this study first assesses the functionality grid's compliance with the theoretical requirements of a paradigm, and secondly its compliance with the empirical requirements of a paradigm.

The theoretical test uses a newly created format, the paradigm template, to establish the necessary criteria. The functionality grid is then subjected to a critical review using the said criteria. It is found that it meets the requirements of a valid paradigm. For measurement of empirical requirements, Kuhn's own criteria are used. This second part of the study involves three practical exercises to examine the practical descriptive power of the functionality grid, and its ability to help first with the formation of a technology attuned mindset of participants, second with the improvement in technological knowledge and third with an increase in the technological literacy of participants. The outcomes of these tests are positive as well. The dissertation concludes that the functionality grid would be a viable paradigm to serve as a guide for the further development of MOT.

The functionality grid becomes confirmed as a paradigm for MOT, because it contains all the attributes to serve as a coherent and streamlined conceptual structure for this discipline. Given this outcome, it is recommended that more effort be invested to understand, promote and popularise the functionality grid; and the various analytical frameworks derived from it. It is recommended that it becomes an explicit part of the book of knowledge for MOT and that it constitutes the basis for an educational curriculum to be shared by every MOT professional and student.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACE	:	Anticipatory, Comprehensive, Engaged
ANOVA	:	Analysis of Variance
CIO	:	Chief Information Officer
CoCT	:	City of Cape Town
CTO	:	Chief Technology Officer
DNA	:	Deoxyribonucleic acid
DRTP	:	Doctoral Training Program
IAMOT	:	International Association for the Management of Technology
ICT	:	Information and Communication Technologies
ISIC	:	International Standard Industrial Classification
IT	:	Information Technology
LEDs	:	Light-emitting diodes
MBA	:	Master in Business Administration
MEI	:	Matter, Energy and Information
MINT	:	Management of Innovation and New Technology
MOT	:	Management of Technology
MOTAB	:	Management of Technology Accrecitation Board
NAEP	:	National Assessment of Educational Progress
NAICS	:	North American Industrial Classification System
NASA	:	National Aeronautical and Space Administration
NSF	:	National Science Foundation
PhD	:	Doctorate in Philosophy
R&D	:	Research and Development
STA	:	Strategic Technology Analysis
TRLs	:	Technology readiness levels
TSoSR	:	The Structure of Scientific Revolutions
UNIDO	:	United Nations Industrial Development Organisation
USA	:	United States of America
USB	:	University of Stellenbosch Business School
WebCT	:	Web Course Tools

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION

Inventors and engineers make technology; entrepreneurs and innovators commercialise technology. Economists debate how to precisely measure the contribution technological innovations make to the economy; managers debate the use of technology, while consumers mostly benefit from technology. At the same time, philosophers continue to debate the question of whether humankind determines the role of technology in the cosmos, and of whether the inverse applies in a society in which the nature and pace of activity appear to be almost entirely determined by technology. Technology is the common denominator in all of these.

Notwithstanding the above, the discipline of management of technology (MOT) is relatively under-represented in the economic and management sciences domain, and as a professional practice it is a low priority on the executive agenda. Upon further investigation it becomes clear that the discipline lacks a coherent conceptual foundation, and that this flaw in its constitution weakens the consolidation and expansion of the MOT body of knowledge. This problem appears to ultimately have a direct bearing on society in general, thereby perpetuating the widespread lack of technological literacy. Technology decision-makers, organisations, and societies at large suffer from a lack of technological literacy. Considering the increasing speed and complexity of technological progress, this means that more and more opportunities for leveraging technology to support and improve the triple bottom line are lost.

In order to advance the formalisation of a conceptual foundation for MOT, this study assesses whether the functionality grid among several incumbent theories in the discipline, complies with the requirements of a paradigm. To offer context towards this endeavour, this discussion proceeds next with a more comprehensive description of the problem statement, followed by a description of various concepts relevant to the understanding of the research problem and the practical business context in which it manifests. Next follows an overview of how the research process is to unfold and a discussion about the relevance of this study. The chapter ends with a view of the limitations of this study.

1.2 THE PROBLEM STATEMENT

Confronted with an ever faster pace of technological progress, and with increasingly complex technologies, decision-makers across the economic spectrum demonstrate a lack of technological literacy, which again constrains the derivation of economic benefit from technological progress. This phenomenon is a symptom of a deeper seated problem ascribed to the lack of a clear conceptual foundation in MOT. MOT is, however, the one discipline in which the field of competence offers itself as the solution to the problem at hand. The discipline is directly relevant to the promotion and enhancement of technological literacy. As a result, it is incumbent upon this discussion to shift the focus to this discipline, and to put its theoretical foundations under the magnifying glass in order to diagnose the precise nature of the research problem and to find more permanent solutions which may bring enlightenment about the nature of technology.

What therefore is the state of MOT? Does it have the concepts and theories to lead the way in the formation of technology knowledge and understanding? From these foundations, does it have the capacity to enhance technological literacy? Typically found within the purview of the faculty of Economic and Management Sciences, MOT is defined as "…a specialised professional practice that harnesses technology-based innovation opportunities…guides technological progress, assesses the potential of individual technologies, and applies this potential to the benefit of business, society and the environment" (IAMOT, 2009: 19). According to Huang (2009: 451), the discipline has a history of 50 years but became more self-sustainable only over the last 20 years. Indeed, rapid cross-continental growth in the discipline followed the often quoted 1987 report by the American National Research Council titled *Management of Technology: The Hidden Competitive Advantage.* Still expanding, diverse in its offering and multi-disciplinary, the subject field has been presented at tertiary institutions for just over 25 years and is now part of Technology and Innovation Management programmes at over 150 institutions (Yanez, Khalil & Walsh, 2010: 1).

Apart from being established as a university teaching programme, the revival of MOT as an academic discipline has led to the formalisation of a scientific discourse about technology and its management imperatives, and then to the creation of International Association for Management of Technology (IAMOT) as a professional society for the discipline.

Of special importance was the subsequent emergence of a broadly accepted Credo for the Management of Technology (Van Wyk, 2003) and a template for graduate programmes in MOT (Van Wyk, 2004a). This template was widely distributed for comment. It eventually constituted a model for a body of knowledge for MOT. This may be called an "exploratory model of knowledge" as expressed in Figure 1.1 (Van Wyk, 2011).

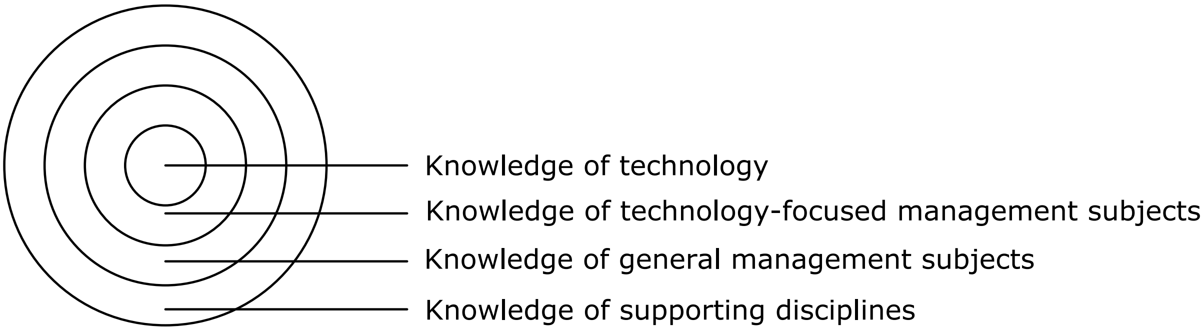


Figure 1.1: MOT body of knowledge: exploratory model

Source: Van Wyk, 2011.

This model has three important attributes. First, it focuses on the unique characteristics of technology; but at the same time it is broad enough to encapsulate the entire scope of MOT as a multi-disciplinary field. Second, it is flexible enough to allow for diversity and unique approaches of host organisations offering the discipline for study. Third, the centrality of “knowledge of technology” is a key feature. This is an area i) in need of high-level tools for professional practice, ii) where teaching materials are in short supply and iii) with vast research potential.

As part of on-going research into the most suitable structure for a body of knowledge, other researchers undertook a number of surveys among stakeholders in the MOT community (Khalil & Yanez, 2006: 2). This led to the formulation of a second model for the body of knowledge – named as the “*status quo* model” (Van Wyk, 2011). This is the model eventually adopted by the IAMOT and that is employed in the manual used by the Management of Technology Accreditation Board (MOTAB) for assessing graduate MOT programmes (IAMOT, 2009: 23).

The *status quo* model renames the various knowledge groups and indicates the relative importance that stakeholders attach to each. When comparing the *status quo* model to the exploratory model, a major point of difference is the degree of centrality accorded to “knowledge of technology”. This is shown in Table 1.1. The *status quo* model prioritises technology-centred knowledge only as third most important, with a weight of 20.8 percent during a first survey, and only fifth with a relative weight of 18 percent during a second stakeholder survey. Yanez and Khalil (2007) confirm the above ranking. In the MOTAB manual (IAMOT, 2009: 22), Management of Technology-centred knowledge gets 40 percent of the available hours of a typical semester course, Corporate Functions gets 25 percent and Technology-Centred Knowledge only gets 20 percent.

Table 1.1: Stakeholder input to importance of template categories

Template Knowledge Group	Relative importance to MOT education	
	Survey 1	Survey 2
Technology Related Knowledge (Management procedures associated with technology intensive organisations such as technology forecasting, R&D management, innovation management, new product management, project management, intellectual property management, integration of technology and business strategy)	25.05% (1st)	24.40% (1st)
Knowledge of Corporate Functions (Classic business functions such as marketing, finance, operations, MIS, human resources, management and business strategy)	21.35% (2nd)	21.02% (2nd)
Technology-Centred Knowledge (Topics such as theory of technology, detailed knowledge of pivotal and emerging technologies, and specialty fields such as electrical, mechanical, information, manufacturing or biotechnology)	20.80% (3rd)	18.00% (5th)
Knowledge of Supporting Disciplines (Examples of courses include national policy frameworks, general systems theory, risk analysis and environmental management, ethics, economics, human behavior, quantitative methods, accounting, and law)	17.16% (4th)	18.23% (4th)
Special Requirements/Assignments (Examples here include capstone courses and projects, internships and business study missions)	15.63% (5th)	18.36% (3rd)

Source: Adapted from Khalil & Yanez, 2006: 2–7.

These rankings demonstrate how MOT stakeholders position themselves away from knowledge of technology as a primary component of MOT. In a subsequent IAMOT forum discussion about the future of MOT, Van Wyk (2008a) proposes knowledge of technology as the foundation for a MOT body of knowledge, depicted in Figure 1.1. However, the template priorities tabled above remain currently employed by MOTAB (IAMOT, 2009: 23).

These conceptual differences originate from the wide diversity of stakeholders in MOT, and in courses about MOT. Van Wyk (2004a: 3) demonstrates the real extent of this diversity. He shows how different types of academic institutions offer academic programmes for MOT, amongst which are business schools, schools of science and engineering, and dedicated centres; how different titles are used for these academic programmes, for example Management of Technology (or Technology Management), Engineering Management, Engineering and Technology Management, MBA Management of Technology and Systems Engineering Management; how programme contents and courses vary among the 148 programmes of which the details are known; and how professional affiliations of the faculties involved vary, with 20 associations listed for these programmes. With the overall community of stakeholders in MOT consisting of policy makers, scientists and engineers, technology executives and investment professionals, this diversity extends to professional culture, tradition and method.

However, the lack of a clear conceptual foundation in MOT is not a new problem. Early in the history of MOT, Farrell (1993: 161), for example, stated that the dialogue about MOT remains in dire need of theoretical structure as "…a unifying perspective to aid in its comprehension….". The immediate result of this shortcoming soon becomes clear, confirmed by Drejer's (1997: 254) concern about the confusion surrounding MOT concepts and the discord in the ranks about practical tools for solutions of technology management problems; and shown by Ropohl (1999a: 66), who finds that "hardly anybody" understands technology; as well as by Phaal and Farrukh (2000: 1) who find little common ground in technology management strategies and practices. Jain and Narvekar (2004) also state that MOT lacks a taxonomy of well-defined concepts, and that the discipline needs a community of practitioners together with a body of knowledge.

The lack of conceptual structure in technology thought ultimately makes for serious consequences. It leads to a theoretical void in the discipline, which again makes for disagreement about the basic essence of technology, and which indirectly leads to a serious lack of technological literacy in society. As is subsequently shown, this situation also makes for yet another dimension of problems, with the role of the Chief Technology Officer (CTO) subdued, and with a lack of understanding of how the all-important invention-to-innovation cycle manifests in practice - in spite of MOT's primary focus upon this cycle. In this regard Cockfield's (2004: 35) plea for a better understanding of technology in the field of law represents a major new front opening up in the problem field, considering the important dependency upon law of inventions, innovations and associated patent rights. Taking into consideration MOT's primary focus, these problems are of a deeply fundamental nature, impacting negatively upon technological literacy, upon capturing of technology-based innovation opportunities and upon understanding and implementing roles and responsibilities of technology decision-makers. However, the manifestation of these problems is not surprising to the keen observer, since from the observations shown here there appears to be a move away from a foundational theory of technology as a conceptual foundation towards technology thought.

In sum, MOT is a discipline which marries technological progress with economic growth. Its primary task is to help professionals capture technology-based innovation opportunities. But from the above it becomes obvious that the discipline faces a serious problem along a critical fault line in its constitution, depicted conceptually in Figure 1.2.

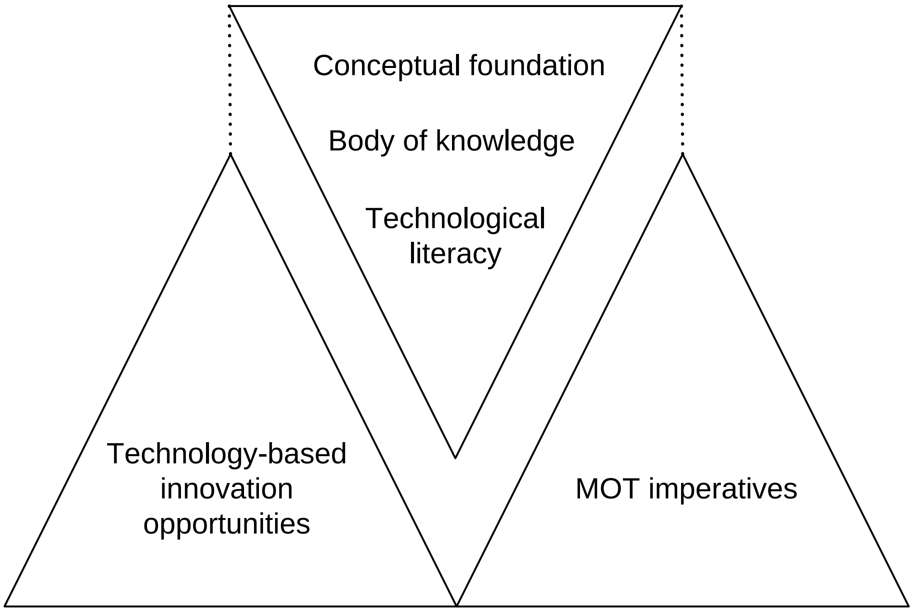


Figure 1.2: The fault line in MOT

Source: Author's own, 2011.

As shown in the above diagram, MOT does not have a clear and coherent conceptual foundation, and as a result it does not have a dedicated and universally agreed upon body of knowledge focusing primarily on knowledge of technology in accordance with a universal structure of technology thought. It ultimately fails in its mandated task to convey technological literacy, which means those professionals who pursue MOT imperatives fail to optimally capture technology-based innovation opportunities.

1.3 RESEARCH AIM AND OBJECTIVES

1.3.1 Research aim

The overarching purpose of this study is to contribute to a clearer and more robust conceptual foundation for MOT. More specifically the study is concerned with ascertaining whether a particular theory, the functionality grid, can serve as a viable paradigm for MOT. To this end the research assesses whether the functionality grid complies with the requirements of a paradigm, theoretically and empirically. For the present purposes, the functionality grid can then be described as a theory comprising a nine cell table juxtaposing technology action with technology output and illuminating the relationship between action and outcome - thus serving as an aid in technology uderstanding. Furthermore, the notion of a paradigm is that developed by Thomas Kuhn (1962), in order to present an alternative view to the conventional positivistic-historical view of scientific advance. According to this view, science advances through a series of revolutions that involve a combination of objective and subjective factors. These revolutions are interruptions in the linear progress of science. Each revolution is marked by the appearance of a new paradigm, which for present purposes can be described as a holistic supra-concept that frames the external dimensions of a field of knowledge, and provides a coherent internal arrangement of its components.

1.3.2 Research objectives

The set of research objectives which flows from the above is as follows:

1. The first objective is to present a short overview of the paradigm discourse, and to extract from this discourse respectively the theoretical requirements of paradigms and the empirical requirements of paradigms.

2. The second objective is to construct a paradigm template which represents the theoretical characteristics required from a paradigm, and similarly to list the empirical criteria required from a paradigm.

3. The third objective is to fit the functionality grid upon the paradigm template in order to assess whether the functionality grid as contesting theory in MOT complies with the theoretical requirements of a paradigm.

4. The fourth objective is to assess whether the functionality grid complies with the set of empirical requirements for a paradigm.

5. The fifth and final objective is to offer recommendations flowing from the results of this study to the MOT community of practitioners.

1.4 RESEARCH STRATEGY

Given the problem statement and the associated research aim and objectives, the question to be answered regarding the research strategy is how to assess whether the functionality grid is a paradigm for MOT. At a more detailed level, the question is how to assess the paradigm characteristics and applications of the functionality grid as a contesting theory in the field of MOT. Assessments have to be made about its compliance with the theoretical requirements of a paradigm, and with the empirical requirements of a paradigm. Clearly, an approach is required which combines theoretical, or basic, research with empirical research.

According to Remenyi, Williams, Money and Swartz (1998: 31), theoretical research involves a study of the established canon of work on a research topic, and building up a new perspective, or theory, which can be added to the existing body of scientific knowledge. Theoretical research does not have empirical evidence as a primary feature, nor as a distinguishing requirement. Against this, empirical research requires empirical evidence, newly collected, and analysed, as part of the empirical exercise.

Empirical research also requires synchronisation with a particular research tradition. In this regard, Remenyi *et al*. (1998: 32) summarise the characteristics of a logical positivist, the most important of which is the notion that the researcher is an objective analyst of a tangible reality. The researcher is therefore independent of the research topic and neither affects nor is affected by it. It is furthermore assumed that independent factors lead to the observed research effects; that supporting evidence is essential; that parsimony is important; and that generalisations about the observed phenomena should follow. Another distinctive trait of logical positivism is quantification and subsequent statistical analysis, in order to meet the requirement of falsification. Logical positivism, however, appears increasingly unpopular with the advent of post-positivism. Schwandt (1990: 259), for example, states that ”… by virtue of nothing else than an accident of birth, all of us are participants in a postpositivistic culture of inquiry. By that I mean we are …in a zeitgeist …characterized by a general rejection of the logical positivist …program of inquiry”. By this statement Schwandt means that social science in particular cannot meet the specific and exacting standards of traditional logical positivism which was meant to serve the natural sciences. This warning is also sounded by Skyttner (2001: 431) when he states that logical positivism lacks in foresight and makes for a diminishing return over a wide front, ranging from social science to quantum physics.

In response to this critique, the taxonomy of research paradigms by Lincoln (1990: 78) is a timely classification framework for researchers looking for paradigmatic guidance. According to this classification, post-positivism is attributed a realist ontology, a dualist and objective epistemology and an interventionist methodology. For example, there may be counter-evidence which traditionally may have left a theory rejected, but in modern social science such counter-evidence should be accommodated as a realistic alternative view of the theory under examination. This allows science to grow and to prosper. Phenomena need not be physically observable after all, i.e. approximations of phenomena are realistic and often form the central tenet of social science research. Furthermore, objectivity remains a regulatory guideline for all inquiry (Lincoln, 1990: 43); also for post-positivism. The subject-object dualism of researcher and researched also remains intact in a post-positivistic epistemology.

So whereas the first phase of this study involves a theoretical approach which focuses on the existing canon of work about the functionality grid, the post-positivistic empirical approach applies to the second phase of the overall research strategy. More specifically, this second phase involves three steps employed to collect empirical data about the paradigm characteristics of the functionality grid. First in this sequence of steps is a set of semi-structured interviews to formally record the impressions of MOT practitioners about the functionality grid. In essence, this method involves semi-qualitative data collection and analysis techniques. The second step in the sequence is a quantitative experiment in order to assess whether the functionality grid enhances technological literacy. The third step is a smaller but no less important dual-nature experiment which continues the assessment of whether the functionality grid enhances technological literacy. It does so, however, with a different yardstick.

In concluding, the overall research strategy comprises a theoretical phase in order to determine whether the functionality grid complies with the theoretical requirements of a paradigm, and a practical phase conducted within the broad parameters of post-positivism, intended to determine whether the functionality grid complies with the empirical requirements of a paradigm.

1.5 KEY CONCEPTS

Management of technology does not happen in isolation. On the contrary, MOT is a multi-disciplinary endeavour, with linkages to many spheres of society and the economy. It is therefore appropriate to provide a brief elaboration of the most immediate concepts which apply to MOT as the discipline is espoused in this study. This discussion highlights how the lack of conceptual clarity in MOT extends to the substance of what MOT practitioners set out to do. In order of relevance, these concepts are respectively those of MOT practitioners, technology, technological literacy, the technology investment strategy, technology tracking and selection, inventions and innovations, technology readiness levels, and technology potency.

1.5.1 MOT practitioners

It becomes clear from the description of MOT that almost everyone who makes decisions about technology will benefit from the discipline, its body of knowledge and its practices. Chanaron, Jolly and Soderquist (2002: 1) describe technology as a “major resource” impacting all management functions. In the typical organisation, individual managers, functional experts and, or, management teams are responsible for technology decisions. Where they can afford it, some organisations have technical experts in Research and Development (R&D) positions with the responsibility for technology decisions as well. The community of technology decision-makers consists of policy-makers, high-tech executives, scientists and engineers, corporate strategists and investment professionals. Encapsulating all stakeholders who make and participate in technology decisions as part of their profession, the term to be used in this study for those who practice MOT as part of their professional responsibilities is henceforth to be "MOT practitioners". These role players are deployed across the spectrum of disciplines and professions which constitute gross economic activity.

1.5.2 A description of technology

According to Cogan (2002: 93), mankind has a love-hate relationship with technology, shaped by a misunderstanding of what technology is. Bond (2003: 128) views the continued lack of agreement about what technology is as a serious obstacle. Shenhar, Van Wyk, Stefanovic and Gaynor (2004: 3) recognise the persistent debate about terminology and set out to redefine "…what technology is and what technology is not". Arthur (2009: 5) states that the term has "…at least half a dozen major meanings…", of which several conflict. Van Wyk (2009a: 4) confirms that the problem of "terminological imprecision" persists insofar it concerns technology. Badawy (2009: 5) helps to explain how the dynamic and fast-changing nature of technology makes agreement about a definition of a moving target. To Aunger (2010: 762) technology indeed remains a concept ridden by confusion.

For the purposes of this study, discussing the various definitions, or participating in the debate about definitions for technology, is not material to the research objectives. Instead, a practical view of technology is taken. Van Wyk (2004b: 23), for example, gives a description capturing the essence of the term, according to which technology is a competence created by people, and consisting of the combination of a device, a set of agreed upon or standardised procedures and the requisite skills. This conception of technology is depicted in Figure 1.3.

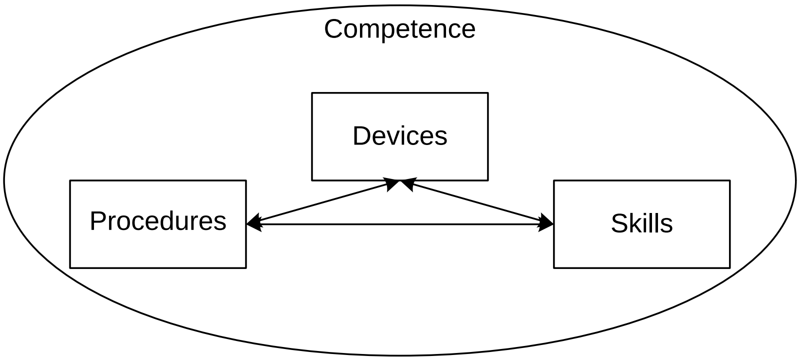


Figure 1.3: The technology constitution

Source: Based on a description by Van Wyk, 2004b: 23.

The interaction between these three elements applies across the life cycle of a specific technology, from initial conceptualisation through design, prototyping, manufacturing, gainful use to retirement. Arthur (2009: 29) allows for yet another useful extension of this description, which is very relevant to this study, when he states that technology as a generic task provides functionality. Competencies, devices, procedures and skills as a combination make for functionality.

The above description of technology must be seen in the context where technology operates on various scales. Together these scales can be conceived along a hierarchy such as that espoused by Shenhar *et al*. (2004). According to this conception, technology can indeed be a basic material such as a paper page, or it can be a complex array of widely dispersed systems which function towards a common mission, such as an electricity grid. This hierarchy is depicted in Figure 1.4.

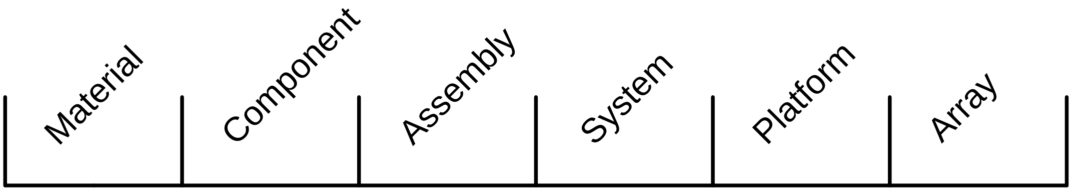


Figure 1.4: The technological hierarchy

Source: Based on a description by Shenhar *et al*., 2004.

Irrespective of their scale, they all comprise of competencies, devices, skills and procedures, and they all progress through a lifecycle from conceptualisation to retirement. The same fundamental principles to manage them apply as a result. Accordingly, Arthur (2009: 43) submits that all technologies share a common anatomical organisation.

1.5.3 Technological literacy

In a study examining the validity of this construct, Hayden (1991) asks pertinent questions about technological literacy. He asks what it is, and what it does. He ponders on whether it is worth studying, and if indeed, how one becomes technologically literate. He explains that technological literacy is not a technical skill in directly applying technology. For the purposes of his analysis, technological literacy is defined as "…general knowledge, abilities and behaviours concerning technology" (Hayden: 2). Hayden however conceives of this competency first as "…industrial technological literacy; and by extrapolation, technological literacy" (Hayden: 11). In his submission about a systems approach for the development of technological literacy, Frank (2005: 31) refers to technological literacy as "…acquiring technological multidisciplinary knowledge, experiencing synthesis and engineering design processes, becoming familiar with the engineering top-down approach, performing cost/benefit analyses, and becoming familiar with the concept of engineering systems thinking, with some principles of project management".

Gamire and Pearson (2006) define technological literacy as "…an understanding of technology at a level that enables effective functioning in a modern technological society". Petrina and Guo (2007: 2) quote the International Technology Education Association's definition of technological literacy as "the ability to use, manage, assess, and understand technology". The steering committee for National Assessment of Educational Progress (NAEP) defines technological literacy, as "…the capacity to use, understand and evaluate technology as well as to understand technological principles and strategies needed to develop solutions and achieve goals" (NAEP, undated: A-8). Their definition encompasses the three areas of Technology and Society, Design and Systems, and Information and Communication technologies (ICT).

As is the case with a definition of technology, these excerpts prove that there are as many conceptions of technological literacy as there are opinion formers on the topic. In fact, Petrina and Guo (2007) state that technological literacy is a deeply contested construct. Studying these conceptions, they include perspectives upon the construct from consumers, managers, analysts, educators and engineers. They are wide and all-encompassing descriptions and appear to cover the cradle to grave lifecycle of technology, which helps to explain why many societies find it a slow and difficult process to become technologically literate in accordance with these standards set. But it also becomes clear from these perspectives that technological literacy evolves from knowledge of technology. Knowledge of technology means to know what any particular technology is, what it is composed of, and what its functions are. Knowing technology follows from the capability to explore the technological landscape and to track and select technology-based innovation opportunities. Knowledge of technology creates technological literacy.

While it is the task of primary and secondary schools to lay the foundations for technological literacy, MOT is most often taught at post-graduate level where its contribution to technological literacy manifests in creating the proficiency to organise technological information and to competently manage technology. It is at this level where management professionals are taught to recognise and pursue technologically-based innovation opportunities, to understand and direct technological progress, to evaluate individual technologies and to apply potential forthcoming from such knowledge and insight to the benefits of their stakeholders. These objectives are encapsulated in the Credo for MOT (Van Wyk, 2003) and they are accordingly structured into syllabi offered by tertiary institutions. But knowledge of technology is a primary requirement in all of the above.

1.5.4 The technology investment strategy

Insofar it concerns the technology investment strategy, MOT practitioners have to have a systematic and logical response to the omnipresence of technology in society. This response comes in the format of a technology investment strategy. The technology investment strategy is the primary vehicle through which technology is leveraged to add value to the organisation and its stakeholders, whether as product, process, service or a combination thereof. The CTO is the technology executive responsible for the technology investment strategy. Smith (2009: 6) describes the CTO position as the executive responsible for dealing with technology as a strategic resource.

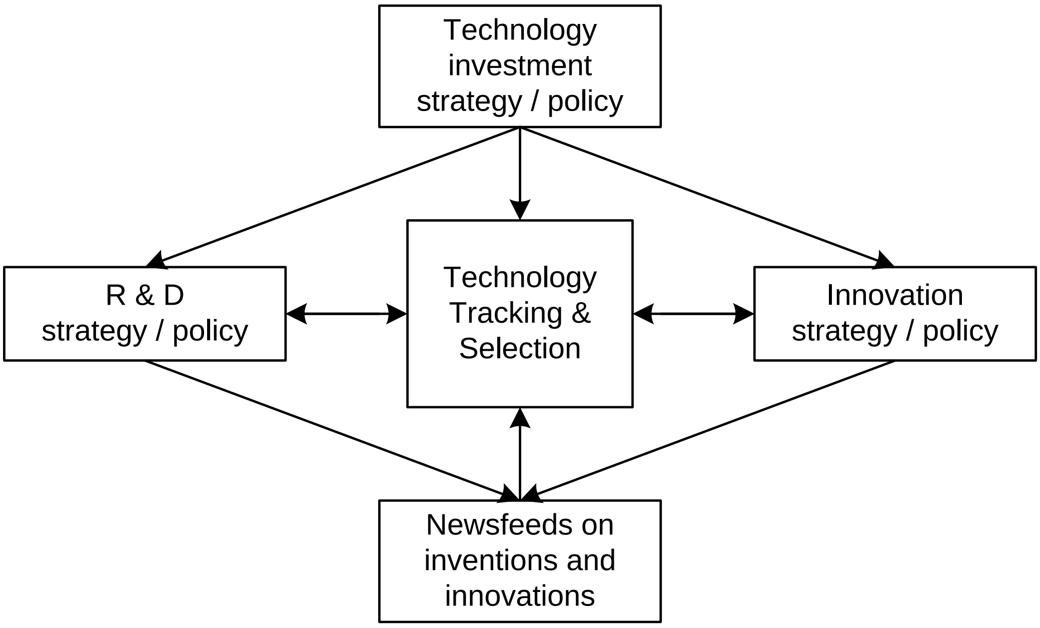


Figure 1.5: The technology investment strategy

Source: Author's own, 2010.

As shown in Figure 1.5, the CTO and associates have a technology investment strategy to execute, and the macro principles which contribute to the business imperatives towards execution of this strategy are found respectively within the R&D strategy and the innovation strategy. All of these strategies have practical policy implications so as to ensure execution. It is ultimately in execution where MOT practitioners are confronted with a wide array of technology choices, and when they have to have the required competencies to make professional choices in capturing the opportunities which come by during the process. Unfortunately, according to Tietze, Lorenzen and Herstatt (2007), and Smith (2009: 7), little has been written about the role and responsibilities of the CTO position. Tietze *et al*. (2007) state that the academic community has not spent much effort in describing the leadership role of the CTO, with a country like Germany mentioned as an example where this role still remains unexplored.

Suffice to state that the CTO depends on a wide array of MOT practitioners across the organisation, among which eminently stand out the scientists in R&D, engineering disciplines from across the organisation and investment analysts in Financial Management. According to Tietze *et* *al*. (2007) coordination between these functions is required in order to ensure effective and efficient decision-making. Yet they still find that numerous difficulties remain unsolved at the interfaces of these vital functions in corporations, often with contradictory objectives and little if any harmonisation.

1.5.5 Technology tracking and selection

A key activity in fulfilling the technology investment strategy is technology tracking and selection. MOT practitioners practice technology tracking and selection to find technologies which would help create economic value. Van Wyk (2009a: 2) describes technology tracking and selection as the practice which helps MOT practitioners to find among a plethora of technological innovations those technologies ready for harvesting. This is in essence what MOT is about – capturing technology-based innovation opportunities and harnessing their potential (Van Wyk, 2009a: 5). According to Smith (2009: 67), CTOs themselves have confirmed that one of their most important responsibilities is to monitor, evaluate and select technologies that may contribute to the organisation’s value. But technology tracking and selection is governed by these macro principles embedded in the R&D strategy and the innovation strategy; and for this activity to function optimally the clever organisation will have a technology intelligence radar screen set up for exploration of the technological landscape so as to receive, process and distribute to the CTO and her associates alerts about new inventions and new innovations. Mortara, Thomson, Moore, Armara, Kerr, Phaal and Probert (2010: 27) describe technology intelligence as ”… the activity dedicated to capturing important technological information and delivering it to decision makers”. In the sense meant here such capturing and delivery happen via the full complement of communication and liaison channels, fine tuned to the parameters of the technology investment strategy. The technology investment strategy in a fundamental way depends on techno-economic realities. In other words, back to economic foundations, where economic growth is predicated on management knowledge of technological progress as it forms the technological landscape in accordance with market forces. The roles, however, of inventions and innovations also have to be understood as part of these economic dynamics.

1.5.6 Inventions and innovations

Inventions fulfill a key role in the economy, because they start every cycle of economic creativity and competition. But this is a role mostly hidden from the public eye in favour of the continuous and much needed process of innovation. New innovations spur economic activity and higher productivity. This helps to lift the growth curve before competing inventions and commercialisation of these inventions lead to famous economist Joseph Schumpeter’s creative destruction and the irruption of a new techno-economic cycle.

It is, however, important that the relationship between inventions and innovations be further explored, so as to show how these processes interact in stepwise sequences. First however, it should be stated that the literature by far favours innovation, with multiple book, journal and conference titles focusing on the description and analyses of innovation systems across the spectrum of industries. In fact, according to Fagerberg (2004a: 4) the literature on innovation became so vast, and so diverse, that a guide to keeping track and understanding this literature collection itself was necessary. Not surprisingly, the discipline of MOT allots a key role to innovation as well. The very definition of MOT encapsulates pursuance of specifically technology-based innovation opportunities. In comparison, the last major attempts to theorise about inventions, according to Arthur (2009: 107), date back to the 1930's.

It is also Fagerberg (2004a: 4) who helps to clarify the distinction between invention and innovation: "Invention is the first occurrence of an idea for a new product or process, while innovation is the first attempt to carry it out into practice". Some commentators, like Palmberg (2004: 186), do not make this distinction, and subsequently persist in including the invention process in their description of innovation, as can be seen in the following statement: "As a minimum requirement all innovations in the database have had to pass successfully the development, prototype and commercialization stages, involving at least one major market transaction".

Fagerberg (2004a: 21), however, helps to further clarify by stating explicitly that "invention" is reserved for the first time occurrence of an idea or concept and that "innovation" relates to the commercialisation of such an idea or concept. Invention is therefore the purely creative process of respectively conceptualising, developing, prototyping, testing, patenting and completing in final form a product or process, and ultimately, abandoning it in exchange for yet another invention at the end of its life cycle. Arthur (2009: 19-21) offers more insight into the nature of inventions, stating that new technologies must always be a combination of existing technologies. In other words, new inventions evolve "cumulatively" from earlier inventions. Interestingly, Arthur credits Schumpeter for this insight with the following quote:"…To produce other things or the same things by different method, means to combine these materials and forces differently".

In comparison to invention, innovation can be seen as a sequence of processes with a commercial imperative, consisting of observing, analysing, selecting, owning and taking to market these inventions as products, processes or a combination thereof. The process of innovation would however typically depend on inventions, because especially for product innovations, inventions appear to be a necessary precondition. But these two processes may follow separate lifecycles as well, such as where an invention does not follow the road of commercialisation and commoditisation, the former which are processes intrinsic to innovation. As is often pointed out

(Fagerberg, 2004b: 7; Frankelius, 2009: 41), innovation does not always constitute of technology either, nor does its manifestation necessarily follow a linear process from R&D to inventions and to innovations. Demonstrated in Figure 1.6, it can be seen how innovation due to its intrinsic character of looking fresh at things may also lead to more inventions. So the processes of invention and innovation are in a truly symbiotic and reciprocal relationship.

As Fagerberg (2004a: 5) confirms, inventors of major technological breakthroughs often do not reap the profits of their inventions. This is not surprising, because the act of creating inventions requires different skills than are required for innovations. For the former, technical and engineering skills are obviously required, while for the latter entrepreneurial skills are required. Apart from the fact that it requires knowledge of technology, and the skills to do technology tracking and selection, in order to ensure a proper investment portfolio, it is also difficult to combine these skills. Smith (2009: 190), for example, points out how innovations start with observation and experience. So when a new concept alights as a new invention, MOT practitioners must be alerted via their technology intelligence radar screens, upon which follows the practice of active technology tracking and selection, with commercialisation and associate purchase decisions the logical next step. But this is not a fixed relationship. It is a relationship subject to market realities and idiosyncrasies. It is also subject to R&D strategies, innovation strategies, and policies flowing from these strategies. For example, if not invented by in-house R&D, MOT practitioners may only be alerted of a specific invention at the prototyping, testing or patenting phase, with every phase adding a premium to the purchase price. Typically entrepreneurial, some MOT practitioners may also resolve to risk, and jump some of the steps in the invention-innovation cycle, like abandoning a promising concept in favour of another, or indeed acquiring patent rights for an invention which showed promising results during prototyping.

Almirall and Casadesus-Masanell (2010) help to bring perspective to the problem of how to deal with open versus closed innovations, and the trade-off MOT practitioners have to deal with in this regard. Specifically, they describe how open innovation systems encourage news feeds, network effects and adoption of scale benefits, i.e. elements and subsystems developed by other market players which may be beneficial to in-house developments, all of which help to create value for innovations. This practice however, is accompanied by the inevitable impact upon the strength of property rights and dilution of proprietary value. Against this, closed innovation systems do not allow networking, because of the premium involved. Closed innovation systems may guarantee more profits in the short run, but in the long run they run the risk of inbreeding.

1.5.7 Technology readiness levels

Technology progress is a fundamental principle in the conception of the technological landscape presented in this study. Van Wyk (1979: 286) gives an account of the basic trends driving technology progress. These trends are as follows:

1. Increasing complexity.
2. Increasing efficiency.
3. Improved size characteristics.
4. Improved time characteristics.

Amidst these trends, MOT practitioners track and select technologies based on whether a technology is ready for investment by assessing technology readiness levels (TRLs). These TRLs are really the respective phases in the creation of a technology, such as those defined by the National Aeronautical and Space Administration (NASA). They range from the very first phase, i.e. TRL 1, during which the basic principles of a particular concept are observed and reported, to TRL 2 during which the technology concept and/or application are formulated, until TRL 9 during which an actual system is mission proven through successful mission operations (NASA, 2010). These TRLs fulfil a key role in the invention and innovation equation, because MOT practitioners especially in open innovation systems want to become aware of promising inventions as early as possible in the lifecycle of the technology so as to ensure minimum investment and maximum profit during commercialisation. Once again, this is a function of information feeds via the technology radar screen and the presence of MOT proficiencies on the processing side, so as to guarantee an optimum take on rate of new technology-based innovation opportunities.

1.5.8 Technology potency

Howey (2002: 79) defines technology potency as relating to an understanding of the possibility of breakthroughs in a technology. Van Wyk (2010: 225) defines technology potency as “the inherent advantage residing in a technology”. Potency ultimately manifests in technology performance which again is a function of technology readiness levels, and which increases with every new product release. So understanding and applying this concept should be an important priority to MOT practitioners in order to best capture innovation opportunities. Potency essentially holds the promise that new technologies will help to achieve higher levels of efficiency, product success and profitability thanks to attributes such as new principles of operation, improved structure, size adaptation, or the use of new materials. Clearly, investing in technologies where breakthroughs are imminent is an important imperative. So, according to Howey (2002: 79), the likelihood of an imminent technical breakthrough may be present when the following conditions hold:

1. A technological trend is approaching a barrier.
2. The said barrier is lower than an ultimate limit.

3. A large, unconquered territory remains for the technology to advance into.
4. The forces promoting technological change are expected to remain strong.

These conditions may not all occur at the same time, and they may be of a deeply technical nature best left to specialising engineers. But MOT practitioners must be aware of their role in technological progress, as well as how they are associated with the respective sets of technology performance metrics which will change in accordance with the functionality and associated output of the technology under review.

There remains, however, a significant barrier to the full understanding and application of the concepts described here in order to capture and harness technology-based innovation opportunities. Given the lack of conceptual clarity in MOT, the structure of technology thought is not streamlined. With the diversity of views regarding a solution to this deep-seated structural problem in the discipline, it is difficult to project a coherent message about technology thought and about technology nature and outcome.

1.6 RELEVANCE OF THE STUDY

The relevance of this study is found in four related and practical features of contemporary society. The first of these, widely acknowledged and accordingly publicised, is the linkage between technological progress and economic growth. Linked to this feature again, is the nature and pace of technological progress, now showing converging trends between different strands of complimentary technologies. In spite of the aforementioned linkages, however, present-day society is characterised by a widespread lack of technological literacy, making for several associated problems, which ultimately result in society not succeeding to optimally capture technology-based innovation opportunities. This feature of society, finally, makes for a magnified effect in the developing world. It is therefore important to demonstrate the relevance of this study by further exposition of these features.

1.6.1 Technological progress and economic growth

Dosi (1982: 147) describes the relationship between technical progress and economic growth as “rather evident”. Thomas (1985: 21) puts into perspective Schumpeter’s description of how “behavioural competition” and “creative destruction” follow when technical innovations with cost or quality advantages reach the market place. In essence, when new inventions hit the market place, they form part of a process of “behavioural competition” between entrepreneurs. These inventions are turned into innovations with higher productivity and higher returns, followed by “creative destruction” and ultimately abandonment of these innovations in favour of new ones. Schumpeter (1966: 83) of course best describes this phenomenon: “…the history of the productive apparatus of a typical farm, from the beginnings of the rationalization of crop rotation, plowing and fattening to the mechanized thing of today – linking up with elevators and railroads – is a history of revolutions. So is the history of the productive apparatus of the iron and steel industry from the charcoal furnace to our own type of furnace, or the history of the apparatus of power production from the overshot water wheel to the modern power plant, or the history of transportation from the mailcoach to the airplane…. illustrate the same process of industrial mutation…that incessantly revolutionizes the economic structure *from within*, incessantly destroying the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism…" (emphasis in the original).

The techno-economic nature of this phenomenon is later described by Neo-Schumpeterians such as Giovanni Dosi, Christopher Freeman and Carlotta Perez, and is meant to highlight the reciprocity between technical change and economy, manifesting in cyclical technological revolutions. That this revolution is all encompassing is confirmed by Smith (2009: 188), who describes Schumpeter's creative destruction as "…the march of invention, innovation, and change …[which] accrues to the good of the entire society". This relationship is best explained by a concept known as techno-economic ecosystems, depicted in Figure 1.6.

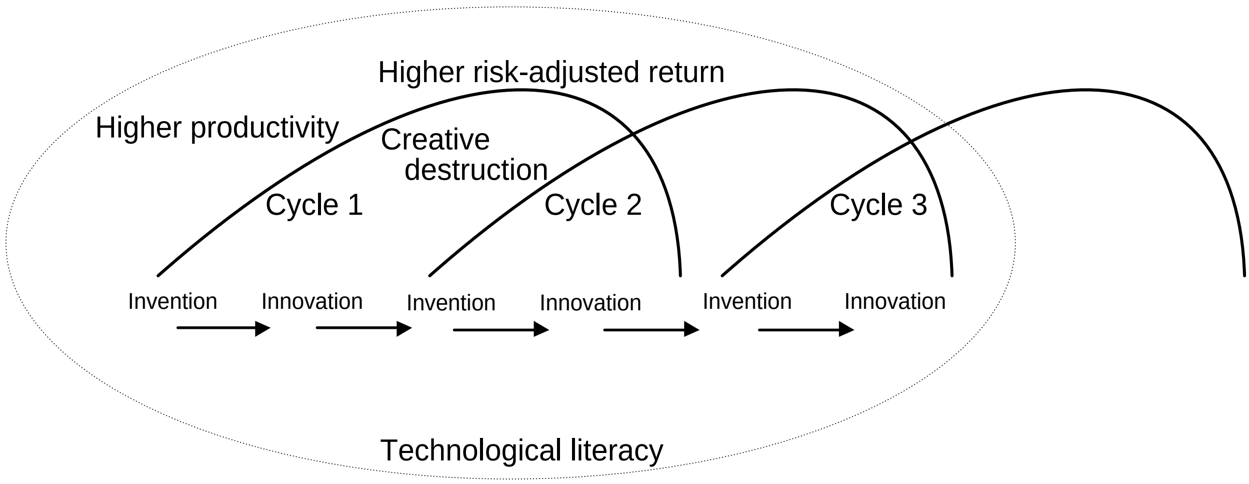


Figure 1.6: The nature of a techno-economic ecosystem

Source: Author's own, 2009.

From a business perspective of strategic management of technology, Grobbelaar (1994: 132) portrays technical change as one of the major drivers of competition at the marketplace. Pol and Caroll (2004: 127) describe it as a basic axiom of economics, while Freeman and Soete (2007: 13) associate the bulk of international economic growth and development theories with accelerated diffusion of technical change and with access to codified knowledge. The notion of technology as a driver of overall economic change came to be seen as so fundamental to an explanation of economic cycles, that manifestations of these technological breakthroughs have been described as "techno-economic paradigms" (Perez, 2002: 8; Sagasti, 2003).

So, the linkages between technological progress and economic growth are clear. But the lack of a coherent and structured conceptual foundation in MOT proves a major obstacle. Without a coherent foundation, of which the architecture is easily understood and generally applied in technology thought, this problem worsens, particularly in the light of the speed of technological progress and its inherent complexity. It is therefore contextually important to present in the next section a bird's eye view of the latest trends with regard to technological progress.

1.6.2 Convergent technologies as the latest manifestation of techno-economic change

Mechanisation of the cotton industry was the driving force behind the 18th century Industrial Revolution. Since then, the world according to Perez (2002: 14) has seen several techno-economic revolutions. They range from steam and railways to steel, electricity and heavy engineering, oil and the automobile with mass production, and then ICT which continues to serve as an economic force multiplier 40 years after it served as a turning point in business computing.

Focusing on the nature of technical change itself, Van Wyk (1979: 294) describes the most basic technological trends driving the ongoing evolution and concomitant change of technology. He points out how the growth of artificial information-processing abilities and the emergence of technologies on micro-scale holds promise to extend human manipulative abilities. Van Wyk (1984: 109) describes how the size of artifacts will increase on the one end of the scale, and decrease on the other. Two developments, i.e. information processing, and micro scale technologies, indeed lead the way for technological innovation in the 21st century. Palmberg, Pajarinen, and Nikulainen (2007: 1), for example, pronounce nanotechnologies as the engine of growth in the 21st century, serving as a basis for technology product paradigms that manifest across borders and across industries. Tegart (2004) describes how nanotechnologies will revolutionise all aspects of the 21st century economy and society. Following Perez, Wonglimpiyarat (2005: 1350) and Kaut, Walsh and Bittner (2007: 1698) view the current installation phase of nanotechnology as a first step towards a new techno-economic revolution, and as a portent towards a next Kondratieff wave.

Biotechnologies, nanotechnologies and ICT as a triumvirate would ultimately manifest in what is today known as so-called convergent technologies. Sagasti (2003) describes this convergence as part of the nature of technological change, involving more actors, becoming more complex and posing more management challenges. These trends are confirmed by Harold Linstone (2004: 187), Editor-in-Chief of the journal *Technological Forecasting & Social Change*, who observes in an editorial about the transition from the Information Age to the Molecular Age the increasingly rapid technological evolution towards convergent technologies.

1.6.3 MOT and technological literacy

Technological change has a direct bearing on the economy, but technology cannot in isolation be properly considered as an economic means. To understand the economic and subsequent management dynamics of technological change, and to leverage such insights for its net benefits, requires technological literacy.

Indeed, the drive towards technological literacy cannot be overstated, given the finding by Van Wyk (2002: 15) that management professionals do not comprehensively analyse new technology, do not trace technology developments and have no coherent view of the technological landscape. This finding must be judged in the light of the fact that businesses have to contend not only with technological change per se, but also with different and faster rates of technological change among different industries (Sood &Tellis, 2005: 155). In fact, Sainio and Puumalainen (2007: 1315) report technology development as one of the most obvious business processes challenging corporate management teams, with the role of technology still lacking in corporate strategic analysis and planning. These realities prompt Lichtenthaler (2007: 1124) to advise that a comprehensive approach to the study of technological change in companies is required to avoid commercial failure. With specific reference to the USA, Van Wyk (2009a) presents an overview of the lack of technological literacy in this country. He refers to the obvious paradox found in the fact that the USA is at the forefront of technological innovation and adoption, yet has been diagnosed as a society not able to think critically about technology, and much less able to make well-considered decisions about technology.

1.6.4 A perspective on technological literacy in the developing world

The general discourse about MOT as shown so far almost exclusively applies to the developed world, where in spite of technological leadership and mastery of innovation it can be said that there is a manifested lack of technological literacy. Even if it can be seen as encouraging that MOT as an academic course is presented in a small number of centres in Africa, South America and Asia, and that the 2010 IAMOT annual conference took place in Cairo, Egypt, this problem of a lack of technological literacy is severe in the developing world. This much is confirmed by Musa, Mbarika and Peso (2005: 112), stating that the developing world lags behind in all aspects of development, and in technology in particular, creating new challenges to developing world societies. Also speaking from a developing world perspective, Sagasti (2005) confirms that there is a large and growing gap between rich and poor countries in their respective capacities to generate and use scientific and technological knowledge. Sagasti also finds growing disparities in economic and knowledge indicators between rich and poor countries, a phenomenon he describes as the "knowledge divide". D'Costa (2006: 10) observes that sweeping changes in technological development over the past 50 years did not lead to fundamentally transformed economic structures in the developing world. Finally, Lochner (2006) serves as a reminder of how a lack of technology related knowledge affects the so-called digital divide.

Among the contributing reasons for the above state of affairs is the extent to which technology transfer remains - even among leading countries in the developing world – a complex debate (Podder, 1988: 63) and a serious hindrance to development (Kirkland, 1996; Hipkin & Bennett, 2004), sometimes leading even to ideological conflict (Georgantzas & Madu, 1990: 81). An associated problem is the matter of protection of intellectual property rights (Cannicea, Chena & Daniels, 2003). According to Wamae (2006), there is ample evidence to show that developing world economies do not have the absorptive capacity to benefit from international technology transfers. This is confirmed by Cetindamar, Wasti, Ansal and Beyhan (2009: 54), who describe technology transfer and adoption as a problem. Aggravating the problem, the state of MOT in the developing world also lacks in exposure, according to Cetindamar *et al*. (2009: 45), who find that there are no review papers of MOT in developing countries.

If at a much more practical and small scale level, one particularly encouraging exception to the above is the focus on so-called "appropriate technologies". This is an initiative supported by acclaimed MIT teacher, Amy Smith, to forego conventional design standards in order to develop simple and working technology-based solutions to everyday problems in the developing world (Design Week, 2009). Musa *et al.* (2005: 112) believe that access and exposure to these basic technologies help to refine mental models, which may facilitate meaningful application of appropriate technologies to solve particularly acute local problems in the developing world. Demonstrating the value of appropriate technologies, Thompson (2006) designs an Internet micro-lending system specifically for East African entrepreneurs who struggle to access seeding finance. Bates (2008) introduces chimney stoves to reduce in-house smoke pollution in rural areas and Thomas (2009) shows how a value chain is to be set up for cassava as alternative crop in Malawi. Oyelaran-Oyeyinka (2010) advocates solar power to meet the African continent's energy requirements, but in his submission states that Africa has failed to appreciate how technological advance drives long-term economic development.

In spite of these isolated success stories, it becomes clear from the above elaboration that the problem of a widespread lack of technological literacy manifests widely across the developing world, and more so because the formal discussion about technology progress, economic growth and the role of technological literacy leans heavily in favour of the developed world. This state of affairs impacts negatively upon the developing world, as economic development is a process of accumulation of technological and social capabilities, according to Perez (2001: 113), which again depends upon technological learning and a complete understanding of the way technology evolves through techno-economic revolutions. Hipkin and Bennett (2004) also view technology knowledge and associated competencies as strategic variables towards competitive advantage for developing countries. With single exceptions the developing world requires the same medicine as does its developed counterpart, i.e. to acquire technological literacy in order to participate in structured and systematic technology thought and to actively practise MOT.

1.7 LIMITATIONS OF THE STUDY

The research strategy for this study consists of two phases, respectively a theoretical analysis and an empirical analysis. This study is, however, not of an applied nature. It should first be seen as a basic study. The primarily theoretical nature of inquiry determines a focus upon internal validity at the cost of external validity. Although the results of the assessment of the functionality grid may hence be considered to be applied in different settings, this study does not intend to claim generalisation of such results.

1.8 UNFOLDING OF THE RESEARCH PROCESS - AN OVERVIEW

Given the above context, this study further unfolds with Chapter 2 first comprising a theoretical analysis about the nature of scientific paradigms and their role in scientific progress. This analysis is based on the original work by the father of the notion of paradigms, i.e. Thomas Kuhn (1962), and the subsequent debate that followed upon the publication of his work *The Structure of Scientific Revolutions* (TSoSR). The purpose of this analysis is to describe the theoretical and the empirical requirements with which a contesting theory has to comply in order to be recognised as a paradigm. The theoretical requirements are then utilised to develop a paradigm template for theoretical assessment of the functionality grid. Due to the intrinsic philosophical nature of the debate about paradigms, the bulk of this chapter leans towards the theoretical requirements of paradigms. In comparison, not much of the Kuhnian debate focuses on empirical requirements, hence a much shorter discussion about this aspect of paradigms.

Balance is restored with respectively Chapter 3 and 4. Chapter 3 offers an exposition of the functionality grid in terms of the paradigm template in order to assess whether this theory complies with the theoretical requirements of a paradigm. In its turn, Chapter 4 represents the main empirical thrust of this study and describes an assessment of the functionality grid for its compliance with the empirical requirements of a paradigm. This assessment constitutes respectively a set of semi-structured interviews, a quantitative experiment and a dual-nature experiment, in that sequence. Chapter 5 serves as the summary and concluding chapter. The research process is depicted conceptually in Figure 1.7.

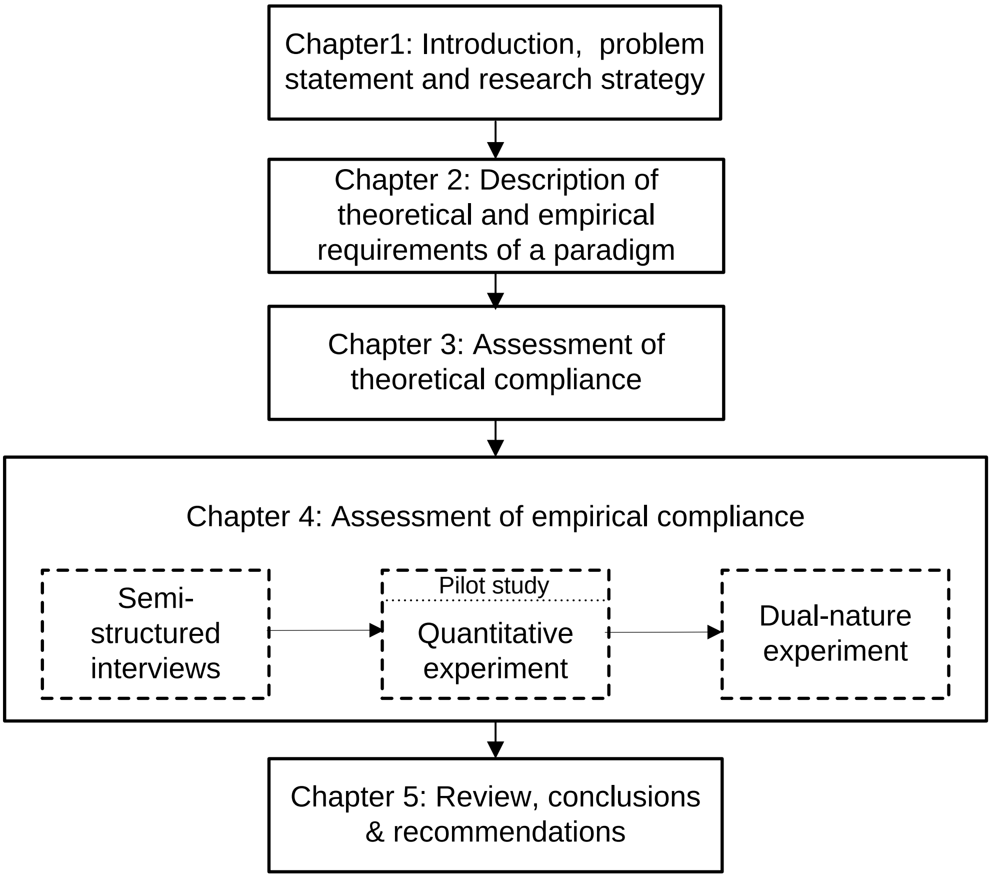


Figure 1.7: Conceptual lay-out of the study

Source: Author's own, 2010.

1.9 CONCLUSION

In comparison to its sister disciplines such as economics, accounting and marketing, MOT is a relatively young and fledging discipline in economic and management sciences. Almost inevitably it must therefore experience growing pains. These growing pains manifest as a multipronged debate about the theoretical core of the discipline, and among others has to contend with the widespread lack of technological literacy in society. This chapter introduces the wider setting in which, and about which, this debate takes place. Specifically, with technological innovations found at the core of economic activity, organisations of all sizes across the globe are faced with a set of MOT imperatives. Meeting these imperatives fundamentally depends on working concepts which form an intrinsic part of MOT, its evolving body of knowledge, and its practical requirement for technological literacy – all of which again depend on stern theoretical foundations. As a result, this study helps to formalise and streamline the conceptual foundation for MOT by assessing whether the functionality grid complies with the requirements of a paradigm.

CHAPTER 2
THE THEORETICAL AND EMPIRICAL REQUIREMENTS FOR PARADIGMS

2.1 INTRODUCTION

The nature, working and role of paradigms in scientific progress have been widely debated since Kuhn's introduction of TSoSR. In spite of the dynamic nature of paradigm activity and the wide-ranging benefits ascendance of a theory to paradigm status holds to a discipline, and in spite of the presence of paradigm activity in MOT, none of this value appears to have deposited in the theoretical debate in this discipline. Yet, it becomes clear from the problem statement that the discipline is in urgent need of an assessment of the nature of paradigm activity within its ranks. For this purpose, more insight into paradigms is needed. Questions such as what paradigms are, how they differ from theory and other academic concepts and how they signal scientific progress need further investigation. For the purpose of this chapter specifically, insights into the nature of paradigms are to be employed to describe the requirements a theory has to comply with to become a paradigm. To this end, a paradigm template which basically describes the form, components and functions of a paradigm is to be created. This paradigm template is to be used to assess whether the functionality grid complies with the theoretical requirements of a paradigm. Further insights into the paradigm discourse, specifically insofar it concerns theory testing and acceptance in practice, are to be used to draw up a list of empirical requirements with which the functionality grid will have to comply in order to be recognised as a paradigm. The first half of this chapter presents a short and critical overview of Kuhn's thoughts about the nature of paradigms and their role in scientific progress, by which is included Kuhn's comparison of scientific progress with scientific revolutions. The second half first describes the systematic construction of a paradigm template for theoretical evaluation of the functionality grid, and concludes then with the listing of empirical requirements for paradigms as these are found in Kuhn's works.

2.2 INTRODUCING KUHN'S PARADIGMS

2.2.1 Contextual setting

Masterman (1970: 59) describes Kuhn as one of the outstanding philosophers of science of her time. Hoyningen-Huene (1993: iv) in the preface to his reconstruction of Kuhn's scientific revolutions, portrays TSoSR as one of the most influential books of the second half of the 20th century. Conant and Haugeland (2000) and Bird (2004) respectively describe TSoSR as one of the most important works of the modern era, and Kuhn as one of the most influential philosophers of science from the 20th century. These are views widely supported by the academic world, even if according to Hoyningen-Huene (1993: iv) the vast amount of secondary literature that followed from Kuhn's works shows a vast range of criticisms, disagreements, praises and applications. Among these the collection by Lakatos and Musgrave (1970) can be seen as a benchmark in the paradigm discourse. Thus a single chapter with the intent to extract the key elements of paradigms cannot do justice to the real width and depth of the Kuhnian debate.

The paradigm template is intended to become a yardstick against which the vital metrics of the functionality grid are to be measured, in order to assess its compliance with the theoretical requirements of a paradigm. According to Kuhn (1970a: 7), "…a new theory is seldom or never just an increment to what is already known. Its assimilation requires…an intrinsically revolutionary process …seldom completed by a single man and never overnight". From this fundamental observation follows Kuhn's conception of scientific progress, with paradigms as central actors. When a sufficiently unprecedented corpus of work attracts a group of supporters away from contesting bodies of scientific work, and when this new corpus of work at the same time poses enough unsolved problems for these supporters to unravel, Kuhn proposes such corpus of work as a paradigm (1970a: 10), and the changing of alliances as a scientific revolution. Gradually attracted to a small centre of agreement, a growing group of scientists rejects and actively deposes incumbent, aging and ungiving paradigms in favour of emerging and maturing paradigms, powered by revised and often fresh theory content, endowed with better applications and more favourable outcomes; and supported by strong centripetal forces in what then evolves into a community of practitioners.

What drove Kuhn to his conception of paradigms as the central actor in scientific progress? According to Mouton (1987: 57), Kuhn's intention with the publication of TSoSR was to present a case, based on the history of science, against the excesses of logical positivism; this with particular reference to logical positivism's conception of matters such as the growth of science, objectivity, observation and testing of hypotheses. Kuhn's central thesis at the time was seen as radical, i.e. to suggest that logical positivism's time honoured methods of rationality and objectivity to solve problems had grown untenable. According to Bird (2004: 3), Kuhn's submission that scientists do not utilise rules in reaching decisions about theories was construed as irrational.

This situation was further exacerbated by Kuhn's rejection of the distinction between the capacity of scientists to distinguish between the psychological process of inventing an idea and the logical process of justifying the idea's claim to truthfully represent reality. Following from this, Kuhn's claim, supposedly, is then that certain kinds of comparisons between theories are impossible. Mouton (1987: 66) helps to disentangle for the layman this argument, subsequently to become known as the incommensurability thesis which, according to Kuhn, boils down to the impossibility of objectively evaluating competing paradigms. This of course becomes the most contentious and persistent topic in the Kuhnian debate, at least from a philosophy of science perspective. Mouton, however, highlights a second important concern, seen from a historical-sociological perspective, namely Kuhn's use of the term "paradigm" and the confusion his use of the term is said to have caused in the discourse about scientific progress.

For the purposes of this study, it is therefore important to first understand what paradigms are, and what they do in periods of normal science, that is, outside Kuhn's periods of scientific revolution. A description of paradigms will help towards building up an understanding of why paradigm dynamics are beneficial for scientific development, and why they hold the potential to benefit specifically an individual discipline such as MOT. It may also serve as a guide towards interpretation of a wider landscape of paradigm dynamics outside the parameters of the theories discussed in this study. With an exposition of paradigms and paradigm dynamics on the blackboard, it consequently becomes easier to understand paradigm contestation, paradigm succession and scientific revolutions.

2.2.2 Paradigms defined

2.2.2.1 An abundance of definitions

Masterman (1970) shows how Kuhn uses 21 different descriptions for paradigms in TSoSR, adding that this makes it extremely difficult for the superficial reader to understand what a paradigm is. Masterman (1970: 65) proceeds to classify these definitions into three main categories:

1. Metaphysical or meta-paradigms, for example where Kuhn equates a paradigm with a set of beliefs (Kuhn, 1970a: 4) or with a new way of seeing (Kuhn, 1970a: 117-121).

2. Sociological paradigms, for example where Kuhn describes a paradigm as a concrete scientific achievement (Kuhn, 1970a: 10-11) or compares it with an accepted judicial decision which "…is an object for further articulation and specification under new or more stringent conditions" (Kuhn, 1970a: 23).

3. Construct paradigms, for example where Kuhn describes paradigms as a set of standard tests and instruments (Kuhn, 1970a: 60) or supplying tools capable of solving scientists' problems (Kuhn, 1970a: 76).

2.2.2.2 The disciplinary matrix as final description

Kuhn gradually concedes that his use of the term "paradigm" may have caused confusion. Already in a postscript to the second edition of TSoSR, he introduces the term "disciplinary matrix" (Kuhn, 1970a: 182), consisting of respectively symbolic generalisations, shared heuristics or commitments, shared values and concrete solutions to problems, also known as "exemplars" (Kuhn, 1970a: 187). When seen in its fullest explanation, this remains the most complete explanation of what Kuhn meant a scientific paradigm to be.

2.2.2.3 The components of a disciplinary matrix

Hoyningen-Huene (1993: 145) suggests that Kuhn's disciplinary matrix consists of five components, i.e. symbolic generalisations, models, values and exemplary problem solutions. He continues to clarify further what each of these components means and does within a disciplinary matrix:

1. By symbolic generalisations, Kuhn refers to formalised, or "easy formalizable" universal propositions regarded by the research community as either natural laws or fundamental equations of theories (Hoyningen-Huene, 1993: 145). To Hoyningen-Huene, these are propositions formulated by philosophers of science, and apart from being empirical laws, they also have the capacity to determine concepts intrinsically linked with their character as universal scientific laws.

2. Models are dualistic. On the one hand, they may consist of heuristic models and analogies, the former which according to a description by Kiss (2006: 302) means they may serve as a set of rules to guide problem solving; and the latter according to Hoyningen-Huene (1993: 146) to treat phenomena of a given class as if they were something else entirely – considering from this author's vantage point that analogies are used to help elucidate and explain a difficult to describe idea with a similarly attributed easier to describe idea. On the other hand, models may be ontological or metaphysical convictions about what there is [exists] and what its fundamental characteristics are. While Hoyningen-Huene distinguishes between these two different kinds of models as components of Kuhn's disciplinary matrix, he states that in their heuristic role they almost do not enjoy mentioning in TSoSR. But models perform for Kuhn all these roles to scientists in the identification of unresolved problems and in consideration of the merits of their solutions.

3. Values gradually fill a very special place in Kuhn's conception of paradigms. Given the objective nature of logical positivism, these values obviously serve as one of the most

significant catalysts in the Kuhnian debate, as is to be shown later. Suffice for the purposes of this particular section of the discussion to point out, via the lenses of Hoyningen-Huene, how Kuhn means values to form the basis for decisions about alternative problem solutions. They operate on two levels in scientific practice, i.e. towards evaluation of individual applications of theory and towards evaluation of whole theories (Hoyningen-Huene, 1993: 148).

4. Exemplary problem solutions constitute the final element of a disciplinary matrix. Apart from completing the wider and more complete description of paradigms, encapsulated in the terms "disciplinary matrix", exemplary problem solutions in a narrower sense are in fact also seen as paradigms in themselves (Hoyningen-Huene, 1993: 154). This demonstrates the dilemma of defining a single conception of paradigms. There are however several reasons for their relative importance within the wider conception of paradigms. Hoyningen-Huene (1993: 159) explains further that as paradigms, exemplary problem solutions fulfil a normative role in a research community. This means they are not only selected as solutions per se, they also serve as a benchmark, for future research to proceed with analogy to these exemplars. This has at least three implications. Firstly, future research must employ the conceptual systems specific to the exemplary problem solution; secondly, these exemplars are used to identify future and as yet unexplored scientific problems in the community; and thirdly, they must be employed in the evaluation of proposed solutions to these problems when they are examined.

Further light is thrown upon the relative importance of exemplary problem solutions within the disciplinary matrix by Bird (2004: 7). Bird specifically highlights Kuhn's examples of classical texts such as Ptolemy's *Almagest* and Newton's *Principia Mathematica*, and describes how, for Kuhn, these texts contain key theories and laws, and how they became paradigms because their theories were in fact successfully applied in the solution of significant problems. As exemplary problem solutions they also contain procedures, instrumentation, scientific language and metaphysics, constituting in themselves paradigms proper.

2.2.2.4 Celebrity status – an asset or a liability?

It is clear that Kuhn had both a narrower and a wider perspective upon the nature of the disciplinary matrix, as these are encapsulated in the description of its constituent parts. Yet, in spite of the introduction of the disciplinary matrix as an effort to conclusively define paradigms, it is very clear to even the most disinterested observer that this notion never was able to transplant the term "paradigm", which has persisted ever since. In fact, contemporary and popular use of the term today may increasingly dilute Kuhn's final and comprehensive meaning of the term. The term may, somewhat paradoxically, be the victim of its own success by virtue of the fact it serves as so many things to so many people that it has as yet not realised its scientific potential as contemporary scholastic notion. Masterman (1970: 59), for example, accuses Kuhn's critics that they have never fully clarified the notion of paradigms for themselves, and that they have simply continued to use the term as meaning either "basic theory" or "general metaphysical viewpoint". While DeGregori (1985: 187) argues that academics should not be too rigid in using intellectual models, because it may stifle the process of solving problems, Mouton (1987: 74) laments the arbitrary use of the term in social science when problem solving as central tenet of paradigm dynamics lacks in these descriptions.

In hindsight, it appears as if Kuhn's effort to clarify what he meant by paradigms failed. Guba (1990: 17), for instance, does not find it surprising that most people, when asked to define a paradigm cannot offer a clear statement of its meaning in the Kuhnian sense. Green, Hull, McMeekin and Walsh (1999: 780) contend that Kuhn lost control of the term and never defined it precisely - this is later conceded by Kuhn himself (Kuhn, 2000b: 221). More recently, Rommel and Christiaens (2006: 610-612) also argue that the term is used too loosely and claimed too easily, without authors showing how their claims meet the Kuhnian frame of reference, and with the inevitable result that paradigms become a "watered-down" misrepresentation of the original.

Given the above, and the central role of paradigms among other academic notions in this study, a clarification of terminology is now offered. For this purpose, a simple sequence of the stages of growth is proposed for the evolution of an academic term to the ultimate status of a Kuhnian paradigm (Figure 2.1).

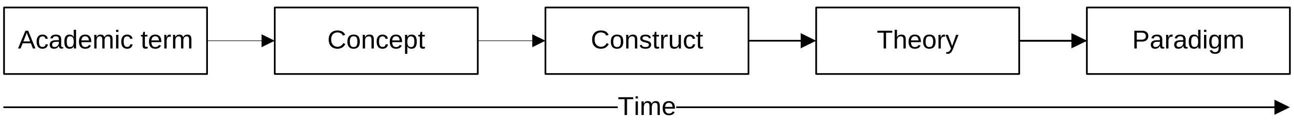


Figure 2.1: Stages of growth: from academic term to paradigm

Source: Author's own, 2011.

An academic term gradually picks up substantial meaning and becomes a concept which explains a phenomenon. The concept attracts attention among academics and practitioners and becomes applied as a construct. Thanks to increased attention, deeper analysis and more application, the construct becomes associated with variables which make explanation of complex phenomena easier. The construct with its variables are seen to aid explanation and prediction of how the phenomena under observation behave, and through further application and testing become recognised as a theory. Given the right academic habitat and circumstances, the theory gradually evolves into a Kuhnian paradigm. In fact, more than an evolutionary process, Kuhn describes the development of a theory into a paradigm as a scientific revolution, because the new paradigm, like a *coup d'état*, only with superior academic force dethrones the incumbent paradigm, or rises to paradigm status where none existed before.

2.2.3 Perspectives upon paradigm dynamics

2.2.3.1 A general overview

Mouton (2001: 141) characterises paradigm thought as a meta-science in his so-called *Three Worlds* knowledge framework. Kuhn (1970a: 10-11) himself states that the "…study of paradigms…is what prepares the student for membership in the particular scientific community with which he will later practice". Kuhn demonstrates his assertions exclusively with examples from the natural science, but as is to be expected from the debate, social science has since significantly benefited by paradigm dynamics as well. This is confirmed by Mouton (1987: 77).

It is now necessary for this study to present a contemporary and academically grounded description of the individual components of paradigms, so as to set the foundations for a paradigm template. To this end, Guba (1990) and Lehman (2004) serve as primary frames of reference.

2.2.3.2 The basic building blocks

Guba (1990: 17) indeed believes that the lack of understanding, and the underdeveloped general conception of the notion allow for new students of paradigms to "reshape" their understanding of paradigms from the foundations upwards. More understanding follows upon increasing study of the notion, and allows for more insight of what it is, what it does and what its implications are. He then proposes that all paradigms share three characteristics, i.e. ontology, epistemology and method (Guba, 1990: 18). These characteristics he explains as follows:

1. Ontology: Serves as basis for ontological questions: What is the nature of reality?

2. Epistemology: Serves as basis for epistemological questions: What is the nature of the relationship between the inquirer and the knowable?

3. Method: Serves as basis for methodological questions: How should the inquirer endeavor to find out the knowable?

2.2.3.3 An expanded theoretical perspective

With these basic elements in place, the next task is to explore paradigms for a more complete description of their contemporary nature. Lehman (2004) presents a comprehensive philosophical overview of the various dimensions of paradigms. He describes respectively a metaphysical dimension, an epistemological dimension and a methodological dimension. Following Lehman and similar sources, these three dimensions are more fully described below:

1. Firestone (1990: 106) describes ontology as “Higher-order theoretical principles about the nature of the world…”. Denscombe (2010: 118) states that ontology refers to the nature of social reality. In following Hoyningen-Huene (1993: 146-147), the basis of the first dimension of the paradigm template can indeed be seen as of an ontological nature, but more is needed to understand the meaning of the term. Lechte (2003) explains how the term ‘ontology’ derives from the Greek meaning for “to be”. The term itself was coined in the early 17th century in order to avoid the ambiguities of the term ‘metaphysics’. According to Lechte, in more recent analytical philosophy, ontology refers to the study of “what is”. The modern thinker of the theme “being” is Heidegger, and as Lechte explains, his requirement for ontology proper was to look at “the being of what is”. So while Koslicki (2005) and Morganti (2009) show how ontology is debated as a specific *branch* of metaphysics, the term is here meant to involve the most fundamental nature of existence, and the study of the essence of existence.

2. The ontological foundation dictates the nature of the epistemological dimension of the paradigm, which conceptually follows upon ontology. Lehman (2004: 19) defines epistemology as the abstraction of the fundamental metaphysical or ontological assumptions of a discipline into theories of knowledge acquisition. From a classical perspective, Bonet, Jensen and Sauquet (2009: 8-9) show how epistemology is a combination of precise propositions which are logical and proven truths, as well as informed beliefs (*doxa*) and practical knowledge (*techné*). Denscombe (2010: 119) explains epistemology as the ways humans create and debate knowledge about their social world and their social reality. Epistemology consequently translates into questions about what knowledge is, how it is acquired, what the body of knowledge for any particular subject field looks like and what practitioners and students know about such a subject field.

3. Epistemology serves as the architectural blueprint of theories, as it lays out structures of thought and organises knowledge into respectively logical and rhetorical domains, from whence it becomes meaningful and useful as problem solutions through paradigm activity. Given this, Lehman (2004: 109) refers to the third dimension as “…rules for theoretical understanding and methodologies for practical application”. He describes this dimension as the first to be concrete and practically employable in science. In following this line of thought, Handfield and Melnyk (1998: 323) describe the role of theory as ”… the vehicle that links data to knowledge”.

2.2.4 What paradigms do in times of "normal science"

Kuhn's paradigms are at the same time catalysts of scientific progress and manifestation of such progress during scientific revolutions. They are exciting prospects, harbouring demise for complacent theories and carrying promise of novelty and stardom to those theories choosing to ride the storm. Even if it remains the ultimate goal, paradigms appear not to comfortably fit into the role of passive meta-frameworks for routine scientific endeavours after they have emerged as paradigms.

Kuhn is well understood and much quoted on periods of "normal science", and how paradigms fulfil their roles during these periods. His description of normal science refers to "research firmly based upon one or more past scientific achievements that some particular scientific community acknowledges for a time as supplying the foundations for its further practice" (Kuhn, 1970a: 10). To have been accepted as these "foundations", hence as paradigms, theories share two vital characteristics, namely 1) they have been sufficiently unprecedented achievements to attract supporters away from competing modes of scientific activity; and 2) they were left sufficiently open-ended to leave all kinds of novel problems for the newly formed circle of supporters to unravel. So, according to Kuhn (1970a: 17-18), to be accepted as a paradigm a theory must "beat its competitors to the post", but it needs not and never does solve all the problems it is confronted with.

Now, according to Kuhn (1970a: 24), all that remains is "mop-up" work, during which scientists articulate those phenomena and theories which the paradigm already accommodates. This work typically consists of theoretical activity and normal run of the mill empirical fact gathering. Theoretical work focuses on predictions where intrinsically difficult theory requires "confrontation" with experiments to move theory and practice closer to each other, to solve real and pressing problems, as well as further theoretical articulation of the paradigm. Practical work consists of revealing with more precision and clarity those phenomena which the paradigm excels in as problem solver, searching for phenomena which intuitively present themselves as natural and practical representations of the paradigm theory and, finally, to search for "residual ambiguities" and to solve them in an effort to further articulate the paradigm theory. However, this final focus deserves more attention, because, according to Kuhn (1970a: 27), it often involves seminal new solutions to problems no-one was interested in solving, given the status as the proverbial black sheep in the family. As Hoyningen-Huene (1993: 167) confirms, Kuhn does not mean to depict normal science as inferior.

From this follows Kuhn's familiar metaphor of normal science as puzzle solver. This is an important analogy, because as is pointed out by Hoyningen-Huene (1993: 171), Kuhn uses this metaphor for science to distinguish it from other creative activities such as the arts or popular philosophy. What is less often stated, however, is that he proposes this metaphor, because intrinsic epistemological or theoretical value is no criterion for a puzzle, but the guaranteed existence of a solution is - if the normal rules of the game are followed (Kuhn, 1970a: 37). These scientific rules are nonetheless comprehensive. They are seen as “commitments”, about which there is consensus - and definitively not disagreement - according to Hoyningen-Huene (1993: 172; 195); and they constitute conceptual, theoretical, instrumental and methodological dimensions (Kuhn, 1970a: 42), which of course can be seen to reflect the typical components of a paradigm.

To conclude, normal science does not intend to cause revolutions. On the contrary, normal science does not aim to propose new phenomena and does not want to invent new theories. It has little incentive to produce major novelties of conceptual or phenomenal nature. From a critical perspective, Lakatos (1970: 155) describes this state of affairs as nothing more than “…a research programme that has achieved a monopoly”. Feyerabend (1970: 207) goes further and questions whether Kuhn’s version of normal science even exists in the history of science. Indeed, in his original submission Kuhn (1970a: 24) suggested that these may be defects of normal science. After all, new phenomena which do not fit into the parameters of the paradigm are not “seen” at all. Inventions of new ideas by others, not measuring up, are rejected. Supporters of the incumbent paradigm are intolerant of these counter-intuitive ideas. However, when these novelties cause puzzles of normal science to end in forms other than the expected and anticipated result, rules are seen to fail. More anomalies are the prologue to discord, change, crisis and scientific revolutions.

2.2.5 The nature of scientific revolutions and the outcomes

2.2.5.1 Overview

In his analysis of Kuhn’s incommensurability thesis, Doppelt (1978: 33) describes Kuhn’s argument as being of an epistemological nature. This is of critical importance for the subsequent analysis of the functionality grid, because as Hoyningen-Huene (1993: 198-199) points out, when Kuhn portrays the nature of scientific progress in the epistemic sense, it is not meant as an analysis of mechanisms by which science affects domains external to itself. For science this is a look in the mirror and a close-up study of the nature of its own progress. What lies outside science in the Kuhnian discourse remains outside, even if terms such as “relativism” and “irrationality” appear in the debate about time-honoured scientific practices.

Mouton (1987: 67) shows how Kuhn’s much criticised variation in use of the notion of paradigms appears to weaken his entire theory about scientific development, because of the central role of paradigms in the process. If there is no agreement about what a paradigm is, then there cannot be agreement about what normal science and its more aggressive opposite, i.e. scientific revolutions, are. Kuhn’s vacillation about definitions for a paradigm should, however, be seen as a result of his evolving views of paradigms and paradigm dynamics during scientific journey spanning a period of almost 40 years. Not taking away from its substance, the foregoing discussion about definitions nevertheless is only a prelude to the wider Kuhnian discourse. This discourse embodies a second and more substantive argument against Kuhn, specifically aimed at his view of theory choice, and the grounds he puts forward for acceptance or rejection of theory (Mouton, 1987: 68-70).

In TSoSR, Kuhn explains that researchers' commitment to a particular paradigm means that their observation of the world and its problems, as well as their use of research tools and concepts, are determined by that specific paradigm perspective. A paradigm shift means therefore that a new reality is observed, and that scientific revolutions give new sense to concepts and their meanings. Mouton (1987: 68-70) summarises the debate when he states that Kuhn's arguments for paradigm determinism of scientific observations, processes and tools form the basis of his fundamental thesis about the incommensurability of successive paradigms. Kuhn (2000a: 228) subsequently describes this thesis as the key innovation of TSoSR. Hoyningen-Huene (1993: 207) reckons the incommensurability thesis as one of the most discussed and most controversial parts of Kuhn's theory. Harvey (1980: 359) describes the "controversy" that followed Kuhn's original submission as a "cross-paradigm" debate.

The primary reason for the incommensurability thesis to have grown into such an important point of debate between Kuhn and his critics is to be found in the fact that theory choice and succession lie at the heart of Kuhn's postulation about scientific revolutions. To fully understand such a decisive contention, the following overview expands on the nature of scientific revolutions and casts light upon theory choice and paradigm incommensurability. The insights brought about by this overview should help create an understanding of the dynamics of paradigm contests, so that these dynamics are to be reflected in the construction and the subsequent application of the paradigm template.

2.2.5.2 Paradigm succession and incommensurability

Hoyningen-Huene (1993: 198-199) explains how Kuhn extends the notion of a revolution to describe theory change where such a change shows an epochal impact within the bounds of a scientific discipline, if not, as happens most often, outside the discipline as well. He also shows how Kuhn uses the notion of a revolution to describe certain scientific discoveries as revolutionary, because for Kuhn they are indeed seminal and lead to corrections in scientific practice and to new world views. Revolutionary scientific development, from Kuhn's perspective, of course cannot be normal. As a result, gathering of knowledge during these revolutionary episodes is per definition non-cumulative in the sense that new knowledge is incompatible with old knowledge, especially because its acceptance implies a change in the lexical structure of the old knowledge (Hoyningen-Huene, 1993: 199). Kuhn (1970a: 15; 102) describes these episodes recognised by the emergence of new knowledge as "conceptual transformations" or "fundamental reconceptualizations". But, as Hoyningen-Huene (1993) shows, Kuhn's conception of this process leads to many misunderstandings.

Given that a new theory typically originates only in the minds of one or a few individuals focusing on anomaly and crisis within the *status quo*, Kuhn indeed (1970a: 144) asks: "What is the process by which a new candidate for paradigm replaces its predecessor?" In practice, paradigm shifts and paradigm formation do not happen in a linear fashion, but at least in theory the sequence appears deceptively simple, depicted in Figure 2.2.

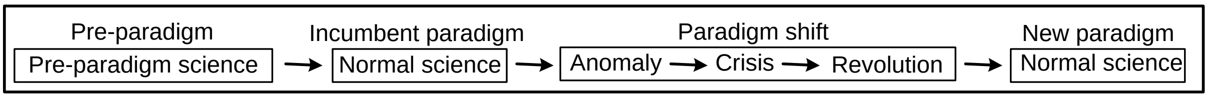


Figure 2.2: The sequence of a scientific revolution

Source: Lochner, 2009.

Kuhn's description of the circumstances involving a scientific revolution appears to the layman demanding and confusing at worst, and difficult to disentangle at best. This is a result of the many combinations with which pre-paradigm science, and existing, or normal, science with incumbent paradigms, manifest towards a scientific revolution. According to Kuhn (1977: 295) some science may still be in development, and may be in a pre-paradigm period, with practitioners of these subject fields split into competing schools of thought, each one claiming control over their subject matter, yet approaching it all differently. This period is followed by a rapid transition, characterised by a notable scientific breakthrough. This breakthrough need not be associated with the first acceptance of a paradigm for the pre-paradigm discipline (Kuhn, 1970a: 179). It is, Kuhn explains further, not the presence of a paradigm during this pre-paradigm period which makes for growth into a mature science, but the nature of the science itself and its intrinsic dynamics. Members of pre-paradigm communities share elements of what constitutes a paradigm, and they may be in competition with other members of paradigm communities who are busy with normal science. All of them compete for dominance (Kuhn, 1970a: 178). In other words, pre-paradigm science, normal science and competition may all manifest at the same time in a fledging discipline, because individuals each experiences the *status quo* differently.

Normal science in this equation does not make for growth, because it is the incumbent paradigm and it rests on its own laurels. The agent of scientific revolutions is the scientific community, according to Hoyningen-Huene (1993: 200). It is these members of the scientific community who ultimately make for change with the breakthrough, and who feel that they have sacrificed for a paradigm change. It also means that there can only be scientific revolutions if indeed there is normal science from where such revolution ultimately is spawned. Kuhn mentions social science as an example where these three modes of existence may manifest, and where conditions of pre-paradigm science may be found alongside conditions of competition and crisis.

Where mature science has acquired paradigms, scientists practise normal science as Kuhn's metaphoric "puzzle solvers" when individuals become aware of anomaly and subsequent crisis in their discipline. The agent for change is, as stated above, the community of practitioners, i.e. a group of scientists, in which increasingly more individuals want change, because of anomaly and crises. Hoyningen-Huene (1993) points out that this is no trivial matter, because the revolutionary nature of the change may matter far more to them than to a distant group of observers to whom the revolution appears as a mere cumulative change. For these scientists to abandon their tradition of normal science in favour of new paradigm conventions, and to convert their entire profession to their new perspective, they have to find failure in the incumbent theoretical doctrines. From the Kuhnian perspective, these breakdowns manifest as the failure of repeated attempts to solve a persistent problem. Aware of the new paradigm, these individuals steadily start to compare and test solutions between the rival paradigms. Kuhn (1970a: 144) states that the new paradigm first emerges only in the mind of a few individuals who learn to see the world differently. Their ability, according to Kuhn, to facilitate change is encouraged by two circumstances unique to them, i.e. 1) their attention has been focused intensely upon the crisis-provoking problem within the normal science endeavour; and 2) they are men and women young to the discipline in crisis and are less committed to the incumbent rules. Indeed, from the above, much of the dynamics of scientific revolutions appear intuitively comparable with a real *coup d'état.*

Hoyningen-Huene (1993: 224-225) explains how Kuhn sees observations, experimental results or theoretical findings that appear to contradict normal science expectations, as "anomalies". The identification of anomalies is, interestingly enough, a unanimous affair in scientific communities, but assessing whether these anomalies challenge the incumbent rules involves a judgment call or an evaluation about which members of the community may differ. Lakatos (1970: 92) reminds that, to Kuhn, revolutions are exceptional, and criticism during normal science, given the incumbent paradigm's overbearing presence, does not exist. Indeed, Kuhn (1970c: 243) confirms this view in his response to his critics in the same volume, here referring to Popper:" He and his group argue that the scientist should try at all times to be a critic and a proliferator of alternate theories. I urge the desirability of an alternate strategy which reserves such behaviour for special occasions".

Conceptually speaking, the change that follows is not a linear process and there is no immediate rejection of the incumbent paradigm which continues to fail in solving the persisting problem. Kuhn's initial position in TSoSR is that ultimate and final verification of a new theory is not the outcome wanted during his conception of scientific revolutions, because no theory can ever be exposed to all relevant tests (Kuhn, 1970a:145); and the question is therefore not whether the new paradigm and its central theory have been verified as successful, but what its probability is in the light of the actual evidence that exists; and how various theories compare in their ability to explain such evidence as supporting the new paradigm and its concomitant theory as an exemplar. The most viable alternative will be pursued, first by a select few, but increasingly by the community of practitioners which constitute the new paradigm. According to Kuhn (1970b: 10), "To rely on testing as the mark of science is to miss what scientists mostly do and, with it, the most characteristic feature of their enterprise".

Much is written about the debate that followed upon the role of testing and the subsequent outcomes during Kuhn's scientific revolutions. Lakatos (1970: 92) explains Karl Popper's traditional positivistic view of theory falsification. Popper sees science as "revolution in permanence". The reason for this is that theories, or "paradigms" in Kuhn's vernacular, are not only tested during scientific revolutions. They are permanently tested and they never are able to achieve and to enjoy the status of "accepted paradigm", to then proceed as a mature science in Kuhn's conception of "normal science". To Popper permanent tests and criticism constitute the "heart of scientific enterprise", and when a theory is seen to fail a test it is rejected. Popper's falsification view is therefore that theories are never justified. Theories must always be subjected to severe scrutiny in an attempt to falsify them. Those theories which survive such scrutiny are then seen as corroborated. To Lakatos (1970: 93), Popper's version of scientific change is "rational", and falls within the logic of discovery. Kuhn's version of scientific change, from one paradigm to another, involves a "…mystical conversion which cannot be governed by rules of reason and which falls within the *psychology of discovery*" (emphasis in the original).

For evaluation of the empirical merits of the functionality grid, it is, however, of paramount importance that Kuhn's position on the role and place of theory testing as part of scientific revolutions is understood, and that his differences with Karl Popper about this matter are seen in the correct perspective. From Kuhn's perspective upon scientific progress, testing is obviously incalculated into the revolution as resolution of the scientific schism that follows upon academic anomaly and crisis. So while he does not agree with Popper about verification procedures, the act of testing is intrinsic to the meta-science principles and criteria later expounded by Kuhn. Kuhn (1970c: 248) in fact states unequivocally that he agrees with Popper about the testability of theories which evolve through the process of theory succession:"…for no theory that was not *in principle* testable could function or cease to function adequately when applied to scientific puzzle solving" (emphasis in the original). Kuhn next equates the terms "anomaly" and "falsification" in his assertion that all scientists must be taught to be on the lookout for theory breakdown, and for opportunities to do so themselves, whether "…it be described as severe anomaly or falsification…"

But a theory in crisis, having continuously demonstrated anomalies, does not simply become falsified, because under these circumstances a falsified theory is immediately rejected, if Kuhn is to follow Popper literally, whereas in practice Kuhn's scientists only gradually lose trust in the incumbent theory and then start to look for alternatives (Hoyningen-Huene, 1993: 237-238). Two grounds exist in Kuhn's exposition for this course of action: First, the theory in crisis must still serve as the standard against which anomalies are identified. Second, a new theory must be measured against the achievements of the old, and must of course exceed them.

Hoyningen-Huene (1993: 215-222; 239-245) describes the principles Kuhn's scientists apply in theory choice. Four categories of these exist:

1. The first category involves the crisis in the old theory. Because the new theory in its infancy at first appears inferior to the incumbent theory, scientists must make a decision on "faith" to work with the new theory. Kuhn's use of the term "faith" here leads to accusations of irrationality in theory choice, but Hoyningen-Huene defends Kuhn by pointing out that "faith" serves merely as a motive for the first adherents of the new theory. It is not a reason per se to accept a new theory.

2. The second category involves the scientific values that the community of researchers adheres to and have along the way reached consensus on. They serve as the meta-scientific framework within which new candidate theories are evaluated during crisis. But these values are "co-constituted" with the actual criteria used to evaluate these candidates, i.e. they must solve as many as possible of the new problems as accurately as possible; and they must also solve some of the old problems better than the incumbent theory did.

3. The third category leverages upon the second. As dissent upon theory choice disappears, and as the new theory proves its mettle, individual members of the research community perceive these new, and successful, results differently – necessarily so, because they are human and maintain different value systems.

4. The fourth category involves the principle of incommensurability. Even if these successive theories are incommensurable, because of the difference in conceptual nature and lexical structure between them, and even if the entire community agrees about the new theoretical solution, there is no logical, exact and rigorously justifiable proof of its merits. Successful applications serve as premises shared by both sides, and values help to sanction the conclusion about the best choice. Logic and experiment play an important role, but values similarly define how individuals resolve their choice. At the same time, there is no neutral language, or lexicon, for the comparison of successive theories. Empirical outcomes derived

from both theories are formulated in concepts with mutually exclusive epistemic claims. Translation happens at a loss of meaning during comparison.

Kuhn (1977: 321-322) himself attempts to clarify the apparent misconception that the adoption of a new paradigm must be based on "mob psychology" and not on good reason. Consequently he suggests five criteria for theory choice, viz. accuracy, consistency, scope, simplicity and fruitfulness. He reiterates at the same time that two scientists using the same criteria may reach different conclusions about theory choice, which brings back the set of principles and values described in the above exposition: "…the criteria of choice…function not as rules, which determine choice, but as values, which influence it…" (Kuhn, 1977: 331).

In his conclusions about this topic, Mouton (1987: 77) describes Kuhn's value to science in general and to social science specifically (also with reference to economic and management sciences for the purposes of this study) as having brought a necessary corrective to the value-neutral logical positivism. Most science outside natural science would normally struggle to make exact predictions, and they would seldom meet Popper's criterion that a science must be falsifiable through the precise and demanding avenue of theory predictions. To these sciences, Kuhn has proposed a working solution with his paradigms. For mature science typically the format would be the manifestation of a discipline supported by one or more paradigms, both of which were refined by scientific revolution, and presenting model solutions which may now be assessed with value-laden criteria agreed upon by its community of practitioners. Looking back, Kuhn's most important contribution is then as alternative to logical positivism the introduction of the notion of paradigms, meant to encompass the origin, growth and evolution of science as problem-solving activity within communities of practitioners. Kuhn (2000a: 227) himself states towards the end of his career that he was always primarily concerned with development of knowledge.

The last word on this topic belongs to Gjertsen (1989). In summarising Kuhn's contribution to epistemology he juxtaposes pre-Kuhnian positivists with post-Kuhnian epistemologists, and then highlights how the notion of scientific revolutions became embedded in the discourse about the history of science and philosophy: "Scientists are well aware how vulnerable their work is likely to be to the critical scrutiny of their successors. Anyone who presents his views as timeless truths is very likely to sink into oblivion when they are overthrown by a later generation…" (Gjertsen, 1989: 27).

Is the functionality grid a paradigm, does it offer a history of evolution as problem solving solution applied by MOT practitioners, or a community of MOT practitioners? Does it have the potential to produce major novelties of conceptual or phenomenal nature? These are important questions for the purposes of the debate in MOT, but to answer these questions a benchmark is required against which the functionality grid can be assessed. The Kuhnian discourse offers the substance for a benchmark, but no immediately available and readily deployable benchmark is to be found as part of this discourse. Given the need for such a benchmark, creating a paradigm template as part of this study is a logical next step.

2.3 A PARADIGM TEMPLATE FOR EVALUATION OF THEORETICAL REQUIREMENTS

2.3.1 Introduction

The paradigm template is an entirely new innovation for the purposes of this study, meant as an embodiment of the primarily theoretical nature of this endeavour. The objective is to capture the theoretical breadth and depth of paradigms within a single template, and to demonstrate how this template can help with a benchmarking assessment of the theoretical requirements of paradigms. This template is next to be described and explained.

2.3.2 Describing the template

Older dictionaries are unanimous about the mechanical nature, or application, of templates, and their role as a guide or gauge. For example, the *Oxford Advanced Dictionary of Current English* (Hornby, 1974: 890) describes the template, or the "templet", as "…pattern or gauge…used as a guide in cutting or drilling metal, wood…". The *New Webster Encyclopedic Dictionary of the English Language* (Thatcher & McQueen, 1980: 862) describes the template as "…a mechanical appliance of several kinds.] A flat thin board or piece of sheet iron whose edge is shaped in some particular way, so that it may serve as a guide or test in making an article with a corresponding contour…". But use of the term has evolved, and not surprisingly, the pace and the direction of development have been set by technology progress. Witness how the online dictionary *Wikipedia* (2010) links the term "template" to Computer Science and Information Technology, Manufacturing and Molecular Genetics, apart from a number of miscellaneous applications. To this author, "template" is not a mere term anymore. It has grown into a modern academic concept with a wide range of applications. In evolutionary terms, it has adapted to survive in the fierce etymological contest to which technical terminology remains subjected as technology progresses at its own superlative speed. As has been stated before, the intent of this study is to leverage the intrinsic power of this concept and to apply it as a construct. Within the bounds of this study, therefore, the term grows from a concept ultimately to be demonstrated as a construct, namely that of a paradigm template.

In molecular genetics, a template serves as a strand of deoxyribonucleic acid (DNA) which sets the genetic sequence of new strands. In its present role, the template is to be constructed and to be utilised to set the "genetic" sequence of a paradigm for MOT. As a result, it is to guide the analysis of paradigm dynamics associated with the functionality grid, and to assess whether the functionality grid complies with the theoretical requirements of a paradigm for MOT. It must therefore set the sequence for observation and analysis of how the functionality grid as contesting theory evolves during a period of normal or pre-paradigm science, how it expands as anomalies appear, and how it emerges from the academic crisis and the revolution that follows as a candidate for paradigm status in MOT. The paradigm template is also meant to make for easier understanding, comparisons, and practical academic applications, of paradigms and paradigm activities.

2.3.3 The merits of a paradigm template

Guba (1990: 17) writes that not casting in stone the "term" paradigm is intellectually helpful. In his subsequent dialogue about alternative paradigms he then undertakes to use the term in its most generic sense as "…a basic set of beliefs that guides action, whether of the everyday garden variety or action taken in connection with a disciplined inquiry". In one very critical way, Guba's undertaking is important for this section. Specifically, a contemporary view of a paradigm template is at most generic. This template cannot possibly contain all the perspectives and all the finer nuances of paradigms as Kuhn conceived of them over an entire academic lifetime. In spite of this qualification, there are several reasons for a paradigm template and they are all supporting of an analysis of paradigm thought within the context relevant to this study. These reasons are as follows:

1. No era can lay claim to exclusivity insofar it concerns the number, magnitude and diversity of problems it has had to face. In Kuhn's terms, paradigms serve as frame of reference for on-going discussions about these problems. Often these problems persist because opposing sides adhere to different and opposing paradigms. To the moderator who has to reconcile these views and who has to help avoid the tipping point posed by many of these pathologies, knowledge of the paradigm discourse may help in the search for middle ground.

2. More than a metaphor, paradigm thought, and paradigm dynamics, from Kuhn's time have been found to serve as a most popular framework for analyses of scientific progress within specific disciplines, across disciplines and across the full spectrum of science. Scientific revolutions represent opportunities for self-examination and reflection of existing beliefs, incumbent theories and standing solutions with their associated practices.

3. At the same time, paradigm analysis highlights salient problems and even pending crisis in the discipline under examination. To this end, paradigms, and hence the intended paradigm template, may serve as a well-timed benchmark against which symptoms can be measured and analysed. History teaches that revolution is a rare occurrence in science. These

revolutions are not easily tolerated, because they may depose of incumbent ruling paradigms. No surprise then, as Kuhn states, that the younger generation, new to the discipline, is more eager to participate.

4. After the revolution, paradigm thought presents the guidelines for conversion. Some may never be converted, and so give effect to paradigm incommensurability to its fullest and hopefully unintended sense, while others may yield and help the discipline in distress to heal and to thrive. Conversion starts with discussions about the merits of exemplar solutions applied to solve pending problems. Conversion involves therefore agreement about these problems at the same time as it involves agreement about the paradigm ready to help solve these problems. Further induction into these exemplar solutions will carry word about the new paradigm and the manner in which it has helped to solve persistent problems not solved by the earlier solutions. This message will lead to early identification, and subsequent timely solution, of more underlying problems not earlier identified because of limited lexicons, limited conceptual foundations and incommensurability between adherents of different paradigms.

Paradigm thought appears unequivocally to be good. A paradigm template is intended to structure and to guide analysis, and to serve as blueprint for recognition of the genetic sequence of paradigm status in the theory under analysis. For MOT specifically, the paradigm template applied is first intended to measure whether the functionality grid complies with the theoretical requirements of a paradigm. But it may also help as guide to reassess fixed view points, to look anew at alternative theories posing and competing as paradigms, and to reconsider their potential to help solve current and future problems in the discipline better than does the incumbent "puzzle solving" inclination.

2.3.4 The paradigm template constructed

Following from the above, the task is now to merge the two notions of paradigm and template into a useful paradigm template. This process follows the sequence of description of form, and then explanation of function.

2.3.4.1 Paradigm template form

According to Morrison (2003), a theory is typically associated with a specific structure resembling a model or a system with discernible building blocks. According to Lincoln (1990: 84), the conventional model of depicting knowledge has always been hierarchical, taxonomical or pyramid like. Lincoln is critical of these notions of accumulation or aggregation, where knowledge is conceived of as a series of building blocks. She sees these models as futile representations of knowledge and states that scientists are "…trying to construct a Tower of Babel, which….will lead us to heaven". Although she thinks the world urgently needs new models of knowledge and knowledge accumulation, she does concede though that there is no new metaphor than the hierarchy, taxonomy or pyramid.

With specific reference to MOT, Jain and Narvekar (2004) propose a straightforward view of paradigms: "Methodologies arise out of a set of assumptions that constitute a way of viewing reality also referred to as a paradigm". They go on to suggest that paradigms are meta-structures, or frames of reference, for questions about ontological, epistemological and methodological matters; a description which of course fits exactly to the foregoing exposition about the nature and role of paradigms. These aspects serve as good motivation for a depiction of the paradigm template as a pyramid, or a hierarchy, reflecting the conceptual status of each of the paradigm building blocks. Depicted in Figure 2.3, the template and its layers reflect the pyramid structure, and the dynamic nature of the interaction between the various layers of the structure.

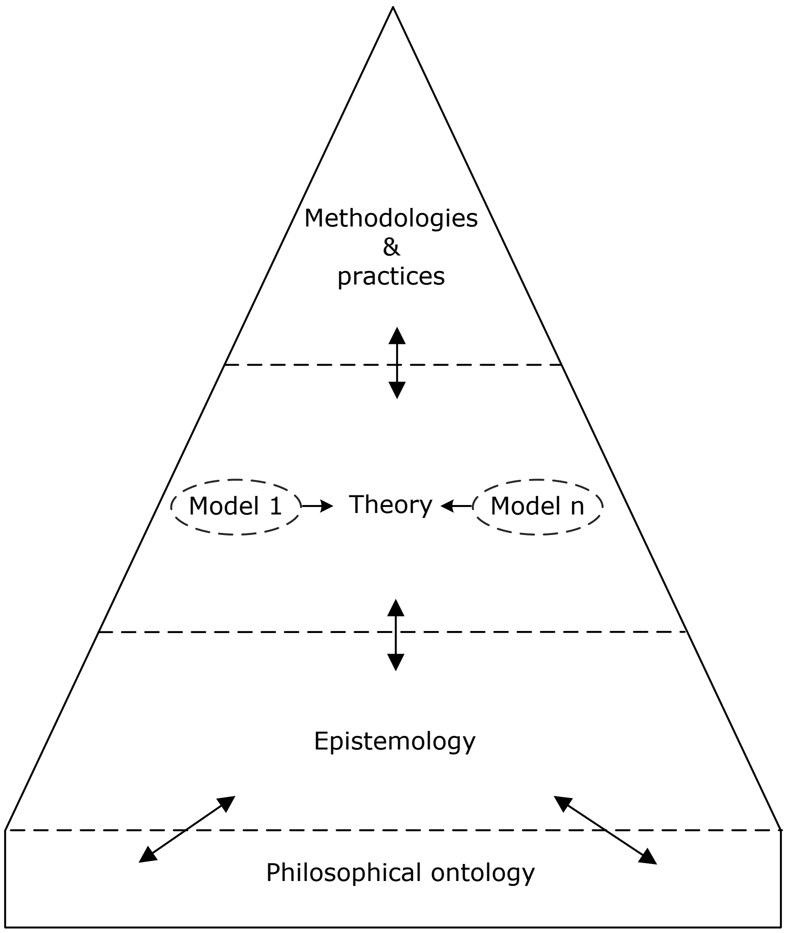


Figure 2.3: The structure of the paradigm template

Source: Lochner, 2009.

The pyramid form lends itself to the idea that at first there must be a metaphysical basis of conceiving the world. This basis consists of the philosophical ontology. Constructed on this foundation is epistemology, from which follows the next layer, i.e. theory together with models. About the presence of models in this equation, Frigg and Hartmann (2006) argue among others that models can represent a theory in the sense that it interprets the laws and axioms of that theory; and that the structure of the model represents the theory which essentially appears abstract to the observer. It makes sense to present theories and models, and their symbiotic relationship, together at this level. A final layer at the top of the pyramid consists of paradigm practices and methodologies. It is important though to state upfront that the paradigm must not be seen as a sum of its components, nor must it be applied for its individual components. A Kuhnian paradigm must be seen in its most holistic sense. Seen from this perspective, and keeping close to the original definition of Holism, a paradigm is indeed more than the sum of its parts. The sum does not add value – it is a mere addition of components. The whole paradigm as exemplary solution adds value, and should be seen as an elevated meta-framework indicative of scientific progress.

Each layer of the template must now be accorded its inborn function, the performing and the sequence of which must be observable and recordable, so as to make possible the assessment of the functionality grid as paradigm for MOT.

2.3.4.2 Paradigm template functions

The ontological layer serves as the guide to assess the most basic and foundational theoretical principles of the paradigm under examination. This layer helps to assess the emerging paradigm's intellectual authority. It asks questions about philosophical substance and searches for answers about the fundamental nature of phenomena taken up and represented in the paradigm under examination. Ultimately, this layer examines existence, and the essence of existence.

The epistemological layer serves to guide the analysis of epistemological claims by the paradigm under examination. First and foremost to assess is whether the emerging paradigm presents an identifiable body of knowledge, and then to examine its structure, its logic and its content. The combination of these components must represent an epistemological function. They must help to define workable propositions, to present answers to existing problems and to illuminate problem areas for further research.

The layer of theory and models serves to guide knowledge creation. This layer presents the logical framework, for new knowledge propositions and for systematic testing of these propositions. The role of models in this layer remains to serve as visible and concrete analogy of theory and its logical content. Assessment involves questions about the theories underlying the paradigm, and it focuses in particular upon the evaluation of the dominant theory. Questions are asked about the nature of the dominant theory, whether it is represented by a model and whether it contains a set of rules or a systematic frame of reference for problem solving. Similarly, the assessment searches for symbolic generalisations of the theory under examination, so as to establish its bona fides and to help towards an understanding of why this theory appears dominant in time of scientific crisis in comparison to contesting theories. The assessor must from this evaluation become convinced that this theory presents the possibility and the potential to convert researchers and practitioners of pre-paradigm or incumbent paradigm science to the new paradigm.

The final layer of the paradigm template consists of methodologies and practices. Here the task of the template is to guide an assessment of whether the paradigm under examination contains practices and or, methodologies. These practices and methodologies are compared to paradigm requirements and questions are asked about the standards they set as exemplars. The assessor looks for conceptual artefacts of note and evaluates whether they have the potential to become solutions to current and future problems. Finally, and of fundamental importance, the linkages between the methods and practices back to theory, epistemology and ontology are assessed as well.

2.3.5 Proposed mechanism for application of the paradigm template

The paradigm template is meant to serve as a guideline and as a sequence in order to measure whether the functionality grid measures up to the theoretical requirements of a paradigm. This template is now completed. It primarily describes therefore these theoretical qualities to be carried by a paradigm, and by way of comparison it is now possible to adjudicate any contesting theory against these qualities in order to assess whether indeed it constitutes of a paradigm. To conclude, the paradigm must have ontological foundations, it must show epistemological substance, it must be active as a contesting theory and it must hold the weaponry of methods, tools and practices. As a unit it must be dynamic and it must comply with form and function as demonstrated in the paradigm template.

2.4 THE EMPIRICAL REQUIREMENTS FOR PARADIGMS

As can be seen from the foregoing, the Kuhnian discourse offers a rich deposit of insights into the theoretical requirements of paradigms. For empirical requirements of paradigms, the focus shifts again to the debate about paradigm incommensurability, and the role of Kuhn's values in theory choice versus Popper's falsificationist position. Following upon this particular debate, Kuhn ultimately appears obliged to describe his criteria for theory choice. Looking at these criteria, they all have a direct bearing upon the empirical quality of theories. For the purposes of this study, these criteria are to serve therefore as the empirical requirements theories have to comply with to become recognised as paradigms. These criteria are accordingly listed below as formulated by Kuhn (1977: 331) himself:

1. Theories must be accurate in their respective domains, so conclusions from tests must favourably compare with the results of existing observations and tests.

2. Theories must be internally consistent, so that they do not contradict themselves; and they should be externally consistent, so they should not contradict accepted and related theories.

3. Theories must be broad in scope and must extend beyond the initial observations and laws which they explain. They must be generalisable to a wider reality than they were initially formulated to explain.

4. Theories must be simple and must bring order, systematic structure and coherence to phenomena not yet meeting these requirements, or to phenomena that would be isolated and disorderly in their absence.

5. Theories must be productive and must yield new predictions, relationships and hypotheses.

Kuhn's criteria for theory choice in fact represent the typical requirements of logical positivism. Their application in Kuhn's terms differs however. Kuhn states that these criteria should be applied within a specific and reasonable context of persuasion, which is another way to bring into the equation the much-debated values pursued by Kuhn's researchers. Consequently, as stated in the description of the research strategy, a post-positivistic stance is adopted in this study for the evaluation of the empirical merits of the functionality grid. This ensures a research course close to Kuhn's criteria, and in particular is meant to show how the practical research results comply with the empirical requirements of paradigms within Kuhn's reasonable context of persuasion.

2.5 CONCLUSION

This chapter offers an overview of the nature of paradigms as expounded by Kuhn. Several works are reflected in this overview where researchers have compared individual theories, models and associated academic constructs with the attributes of Kuhnian paradigms. The work by Guba reflects this best, representing a dialogue about the paradigm status of four alternative, and contesting, research approaches viz. positivism, post-positivism, critical theory and constructivism. Others, like Lehman with Systematic Theology, assess paradigm dynamics in individual disciplines. From this overview flows an evaluative framework for assessment of the merits of the functionality grid as a paradigm for MOT. This framework comprises of the paradigm template for the assessment of the theoretical merits of the functionality grid, and a list of empirical requirements for paradigms. Of these two sections, the paradigm template is an entirely new creation for the purposes of this study, whereas the shorter list of empirical requirements is based on Kuhn's much debated criteria for theory choice. Application of this framework follows next.

CHAPTER 3

ASSESSMENT OF THEORETICAL MERITS: FITTING THE FUNCTIONALITY GRID TO THE PARADIGM TEMPLATE

3.1 INTRODUCTION

This chapter describes how the functionality grid is fitted to the paradigm template in order to assess its compliance with the theoretical requirements of a paradigm. In accordance with the nature of the discussion set in the previous chapter, this evaluation and the associated discussion remains of a theoretical nature. It does as yet not present exact empirical parameters, nor measured outcomes. Following on the introduction of the functionality grid, the sequence to follow for the evaluation itself is already set by the paradigm template. The first step is to describe and analyse the ontological foundations of the functionality grid. A discussion of the epistemological nature of this theory follows. Next in the sequence is a discussion about the nature of the theoretical contest to be observed in MOT, with specific reference to the functionality grid in this regard. The next step in the evaluation is to present an overview of method and practice in MOT, with specific reference to the role of the functionality grid. A final step is to evaluate the behaviour of the functionality grid as an integrated unit in relation to the MOT environment in which it finds itself. This view is from a MOT perspective upon the functionality grid and it focuses upon paradigm dynamics within the discipline. The chapter concludes with an overview of the results of this template evaluation and sets the stage for deeper analysis of the empirical qualities of the functionality grid.

3.2 THE FUNCTIONALITY GRID: AN INTRODUCTION

The functionality grid appears as an intellectual and philosophical discovery which in the Kuhnian tradition may yet evolve as a worthy contender for the position as paradigm for MOT. During the 1970's, functional analysis as the forebear of the functionality grid broke ranks with existing dogma in a decade which, according to Frederick Ferré (1995), was characterised by failure of the philosophical profession to debate technology with the urgency and seriousness it deserved. It was a decade in which the intellectual milieu had to deal with "…the Vietnam War, the growing sense of threats to the global environment, and the rise of feminist, racist, and classist issues in the overall atmosphere of the Cold War…" (Ihde, 1995). It was also a decade confronted with faster than ever technical progress and the irruption of a revolution in information and communication technologies (Perez, 2002: 14), accompanied by inevitable symptoms of increasing automation and changing labour-work relations. It was, finally, an era which saw the philosophy of technology taken beyond its "preparadigmatic jumble", according to Borgmann (quoted in Durbin, 2006: 188).

Originally from the German school of philosophy, the argument for functional analysis of technology as it appears in *Eine Systemtheorie der Technik* (Ropohl, 1979), and later in *Allgemeine Technologie* (Ropohl, 2009a) is a response to the need for better understanding of technology by philosophers, economists and society at large. Pursuing a consistent and systematic framework for analysis of human-technology interaction, Ropohl (1999: 66) states that he resolved to use Ludwig von Bertalanffy's conception of General Systems Theory as a "powerful tool" to have formulated his philosophy for socio-technical systems. Depicted in Table 3.1, Ropohl's subsequent contribution is a nine cell matrix which distinguishes between functional classes and outputs, for authenticity's sake presented in its original format.

Table 3.1: Ropohl's original nine cell matrix

Funktionsklasse		Handlung	Transport	Speicherung
Output		Produktiontechnik	Transporttechnik	Speicherungtechnik
Materie	Materietechnik			
Energie	Energietechnik			
Information	Informationtechnik			

Source: Ropohl, 1979: 178.

Ropohl, a German philosopher, expounded socio-technical theories which are substantive to the philosophy of technology. Consequently, the nine cell matrix is submitted as part of an on-going effort to promote better understanding of human technology relations. But it is Van Wyk (1979; 1984) who first introduces Ropohl's work about functional classification to the English world of science, describing the matrix as a "…simple, and highly descriptive…" technology classification scheme (Van Wyk, 1984: 106), as demonstrated in Table 3.2.

Table 3.2: Ropohl's matrix introduced by Van Wyk

Basic classification of technology

Major output	Mode of manipulation		
	Processing	Transporting	Storing
Matter (M)	Ore crushers, blast furnaces	Trucks, trains and aircraft	Shelves and containers
Energy (E)	Generators and motors	Electricity, transmission cables	Batteries
Information (I)	Electronic calculators	Radio transmitters and optic fibres	Books and magnetic memories

Source: Van Wyk, 1984: 106.

Van Wyk's work with the nine cell matrix continues to evolve and later leads to the introduction of the matrix as a "nine-cell functional classification" scheme which forms part of a wider technology analysis framework known as Strategic Technology Analysis (STA) (Van Wyk, 2004b). The introduction to the above work states, not unexpectedly, that the nine cell matrix as a coherent view of technology represents a paradigm shift, the importance of which is still to be fully realised and harnessed for the common good. The nine-cell functional classification appears in Table 3.3.

Table 3.3: Van Wyk's nine-cell functional classification

		Ways of handling		
		Process	Transport	Store
Aspects handled	Matter			
	Energy			
	Information			

Source: Van Wyk, 2004b: 34.

At least one critically important outcome of this development is to be demonstrated as this chapter unfolds. More specifically, it involves the evolution of the nine cell matrix from a mere concept in a theory of socio-technical systems to a theory applied in technology exploration and in a wide range of academic and educational settings where technological literacy is pursued. The nine cell matrix can therefore be seen to evolve from a mere diagram conceptualised by Ropohl, to a theory which is practically applied and which gives effect to theoretical propositions about knowledge of technology and technological literacy. In its latest and most refined form, Van Wyk (2009b) describes the theory as the "functionality grid", and actively applies it in the format depicted in Table 3.4. From this depiction, it can be seen how the functionality grid has evolved from the concept status to the theory it is today. It is now used to explain and predict the relationship between technology-related variables, i.e. output and action, and these relationships are used to help place difficult to understand technologies in the grid. From here, it becomes easy to understand what the technology under observation targets, i.e. either matter, energy, information or a combination thereof, and the action of the technology under observation, i.e. to either process, transport, store or a combination thereof.

Table 3.4: The functionality grid

Positioning this technology in the functionality grid

		Action		
		Process	Transport	Store
Output	Matter (M)	Transforming substances	Moving substances	Holding substances
	Energy (E)	Generating energy	Transmitting energy	Keeping energy
	Information (I)	Composing information	Sending information	Saving information

Source: Van Wyk, 2009b.

3.3 GOODNESS OF FIT EVALUATION

3.3.1 Ontological foundations

The ontological roots of the functionality grid are to be found in a short analysis of several fields of thought, which can be seen to have a defining influence upon each other and consequently upon the nature of the functionality grid and its representation of technology. These fields of thought are represented next as respectively the basic ontology of technology itself, specifically as formulated by the German philosopher Martin Heidegger, seen together with Jacques Ellul as the founding fathers of the discipline of Philosophy of Technology (Albert Borgmann quoted in Durbin, 2006:188); the philosophy of Holism, the father of which is South African statesman and philosopher Jan Christian Smuts; as well as General Systems Theory as espoused by Ludwig von Bertalanffy. With these fields of thought first structured and presented, the next logical step is to compare how the functionality grid serves as a proxy for the main actors and principles identified during this process.

3.3.1.1 An ontology of technology

Belu (2005) and Belu and Feenberg (2010) present critical accounts of Heidegger's ontology of technology. Belu (2005: 573) describes Heidegger's view of technology as "dystopian" and a "historical destiny" for the West. This view of technology, according to Belu (2005: 573) represents an essentialist interpretation of technology, against the alternatives proposed such as seeing technology as political, ethical and aesthetic. For Belu (2005: 577) Heidegger's technological age is defined by "the structural loss of the autonomy of the subject and by the subordination of both subject and object to the demands of the network". To Heidegger, therefore, modern technology is not seen as the action of autonomous subjects in relation to objects. Rather it is a case of resources engaged in "networks of optimization". Heidegger's technology represents an ontological presence larger than regional concerns such as politics or aesthetics. In fact, technology is a condition for these (2005: 580). Belu describes this state of affairs as a hegemony of "Gestell".

Belu and Feenberg (2010) cast more light on the above. They explain how Heidegger uses the neologism "enframing" ("Das Gestell" in German) to describe the essence of the technological age. Enframing is a historical mode of revealing which sums up the possibilities of the technical age according to the imperatives of ordering, control and efficiency (Belu & Feenberg, 2010: 2-3). In fact, enframing sums up the total possibilities of any and all types of machine technology and represents the fundamental structure of being. It is ontological, according to Belu and Feenberg. It is furthermore an essential dispensation without which machines cannot exist. Ordering is to be seen as a fundamental quality of the "technical lifeworld". For the modern age, the essence of modern technology is to seek to order everything so as to achieve more and more flexibility and efficiency.

Heidegger's ontology of technology, in this author's view, appears as the early forerunner of a philosophical perspective upon technology which has since been described as technological determinism. Landeweerd, Osseweijer and Kinderlerer (2009: 533) present a contemporary overview of what technological determinism is, and how it compares to the philosophical view which developed in response to it, i.e. social determinism. According to them, technological determinism holds that technology and technological progress lie at the basis of society. In other words, technology determines the nature and pace of change of society. Actually, technology is seen as the exclusive driver of societal change, where influences such as politics, ecology, or ideology are all reduced to technological forces. The role of science is in support of technological progress. In alliance, these two forces determine what happens in the world. Arthur (2009: 11) puts into words how deeply engrained this philosophy has become into the modern world:" This is not just because technology creates much of our world. It is because technology at this stage in our history weighs on us, weighs on our concerns…Technology is steadily creating the issues and upheavals of our time". Yet, comparing technology to the force of nature offers the boldest expression of this stream of thought:" The technium is now as great a force in our world as nature…" (Kelly, 2010: 17).

Against this, social determinism is characterised by traditions such as Marxism, social constructivism and cultural determinism, holds that social factors determine the nature and pace of technological progress and innovation. According to this view, history is determined by societal forces, and this applies to the history of science and technology as well (Landeweerd *et al*., 2009: 535). Society drives history and determines the norms for science and technology. In social determinism, specifically social constructivism, it is not nature, reality or any other forces which determine history, but social and cultural norms together with settled conventions that guide the development of scientific knowledge and its application in technology. Whether a technology is accepted is solely based on its level of acceptance in society. Skyttner (2001: 430) expresses this world view best in the following admonishment: "Don't trust technology and don't trust those who trust it…".

Technological determinism and social determinism are mutually exclusive approaches. They represent a natural field of tension in the development of an ontology of technology. Theirs remain a very relevant and persistent dividing line. But the elements and principles forthcoming from this dialectic leave behind much to help determine and analyse first the ontology of the functionality grid, and second the epistemology of this theory. These elements are respectively technology, society and history, and the principles such as structure, order, control, flexibility and efficiency.

3.3.1.2 Holism as an ontological foundation

A next field of thought which helps to structure the ontological foundations of the functionality grid is the philosophy of Holism. Not generally recognised for its intellectual authority, according to Zeleny (1979: 17) and modern time Smuts authority, Piet Beukes (1989: 11), Holism is the brainchild of J.C. Smuts. Smuts' work titled *Holism and Evolution* first was published during 1926, which was a particularly unfortunate time for such a work to appear, given the economic conditions preceding the Great Depression; and so too the 1938 publication of the German translation of *Holism and Evolution* just before the Second World War. Still, this work ran into three editions in England, while a special edition was published in the USA (Smuts Jr., 1952: 287).

Smuts coined the word "Holism" from the original Greek term "Holos" meaning whole (Smuts, 1987: 98). Holism's essence lies in a "…unity of parts which is so close and intense as to be more than the sum of its parts" (Smuts, 1987: 86). This unity does not only give a particular conformation of structure to its parts; its power of synthesis is so strong that it alters the functions of systems. The parts function towards the whole, and the whole and parts appear to reciprocate each other. In Smuts' own words: "A whole, which is *more* than the sum of its parts, has something internal, some inwardness of structure and function, some specific inner relations, some internality of character or nature, which constitutes that *more*…Wholes are therefore composites which have an internal structure, function or character which clearly differentiates from mere mechanical additions…we see structure becoming secondary to function, we see function becoming the feature of the whole, we see it as a correlation of all the activities of the structure and effecting new syntheses which are more and more of a creative character" (Smuts, 1987:103-104) (emphasis in the original).

Smuts (1987: 122) concedes that the concept of wholes, as espoused by Holism, is a generalised structure and an abstract schema, hence a framework to be applied to any particular case. To Smuts it is indeed the structural or schematic character applied to a phenomenon which brings it close to the concrete character of human experience. The fundamental unity of parts of the whole, and said reciprocity, bring about a unity of action, shown by the regulatory power of the whole over its respective parts. Apart from its structural and functional roles, Smuts allocates, from the perspective of this discussion, very familiar-sounding attributes to Holism. Among these are its quality of organisation, co-ordination, regulation and control (Smuts, 1987: 142-143). Given subsequent developments in the ontology of technology, and with specific reference to the Heideggerian view upon the fundamental essence of technology, Smuts concludes with a particularly revealing comment: "The individual in society is born into a vast network of controls, and from birth to death he never escapes it subtle toils"(Smuts, 1987: 342).

In his review of the discourse about the philosophy of technology, Durbin (2006) adequately shows that Holism represents a particular worldview, and therefore represents an ontological statement of which the implications are wide and all-encompassing. Zeleny (1979: 21) confirms the status of the Smuts philosophy when he describes it as "…another general systems theory par excellence…", and Skyttner (2001: 46), finally, states that through his book of Holism and Evolution Smuts must be considered as one of the "most influential forerunners of the systems movement".

3.3.1.3 General Systems Theory as ontological foundation

The profound influence of Holism is confirmed through yet another avenue. The father of modern General Systems Theory, Ludwig von Bertalanffy, writes in 1971 (quoted in Zeleny, 1979: 21) how his theory is ultimately a “logico-mathematical science of wholeness”. After his own overview of Cybernetics and General Systems Theory, as well as that of Tektology as the Russian version of a theory of organised wholes, Zeleny submits that surely the combination of these theories presents a course for further analysis of real world problems (1979: 23). Von Bertalanffy, according to the *Cambridge Dictionary of Philosophy* (1999), proposed General Systems Theory in reaction to scientific reductionism and as an effort to revive the unity of science. Thus, the same concepts and principles of organisation underlie different disciplines such as Physics, Biology, Technology and Sociology, to name a few, constituting a basis for their unification.

Demonstrating the world view which evolves from these broad values, Ropohl (1999: 62) summarises three contemporary perspectives of systems:

1. Systems are best known as structural concepts. According to this view, a system consists of a set of elements and a set of relations between these elements.

2. Systems as functional concepts are equally popular. According to this view, a system constitutes an entity which transforms inputs into outputs, depending on specific internal states.

3. A final view of systems is that of a hierarchical concept, where system elements are regarded as subsystems.

Typically, according to Ropohl (1999: 62), these three conceptions of systems are unified within General Systems Theory, and the most general principles relevant to this philosophy remain applicable at a generic level to all conceptions of systems. These principles are as follows:

1. The system is more than the set of its elements.
2. The structure of the system determines its function.
3. System function can be produced by different structures.
4. The system cannot be described on just one level.

Ropohl (1999: 64-65) elaborates on how General Systems Theory offers a uniform language for describing and explaining diverse phenomena. Critics of General Systems theory, on the other hand, complain that the theory merely serves as a translation of specific disciplinary language into a generalised language. However, it brought along several benefits. These benefits are found in the manner in which the theory contributes to problem solving where different expert languages make cross-disciplinary work difficult. Specifically, General Systems Theory presents a wide range of expressions, including 1) the formal language of set theory, which may be used for qualitative language and may also be specified in mathematical terms; 2) graphic representations, which make illustration of complexity much easier than does verbal language; and 3) verbal interpretations of formal and graphic terms, which correspond with specific science languages as the background of rational precision. This latter point is confirmed by Skyttner (2001: 43), stating that one of the most important contributions of General Systems Theory is its provision of a single vocabulary and a unified set of concepts which can be applied to the entire collection of science.

Ropohl concludes that instead of suppressing diversity, General Systems Theory constitutes of a new level of unity beyond disciplinary specialisation much needed in an era of over-specialisation. In an era where atomistic trends prevail and lead to complications with understanding and problem solving, General Systems Theory offers a holistic representation of system connections and interrelationships between the respective parts.

3.3.2 Ontological manifestations

When the functionality grid is examined for its ontological foundations, five questions must be answered:

1. What is the history of this theory and what societal impact was it meant to have, if at all?
2. How do the principles of structure, order, control, flexibility and efficiency reflect in this theory?
3. How does the principle of unity versus parts manifest in this theory?
4. How does the principle of structure versus functionality manifest in this theory?
5. How does the theory present descriptions for technological systems?

Ropohl (2009b) is on record regarding his view of the West German society of the 1970s, which is when he first penned *Eine Systemtheorie Der Technik* which formed the wider intellectual context for the first version of the functionality grid, i.e. the nine cell matrix. He describes it as a period characterised by scientific and political unrest, an era when young people easily may have become confused by fast changing fashions. The debate about technology and technique had disappeared into oblivion after the Second World War, to be revived during the 1960s with topics such as the role of technology as imperialist tool and the influence that continued automation and mechanisation would have on production, and jobs. The student movement was characterised by a so-called Marxist renaissance and important philosophical debates about the merits of logical positivism took place. Apart from philosophers, student movements and unions were instrumental in these debates. During the early-1970s the impact of nuclear technology became an important topic as well, and together with this came the ecological movement. Ropohl (2009b) describes how this environment influenced his intellectual development during the late 1960s, especially since he was at the time involved with the integration of manufacturing technologies, which allowed him the opportunity to learn about the socio-economic impact of technology. Combined with his introduction to Cybernetics as the control perspective upon General Systems Theory, these perspectives led him onto new intellectual vistas.

Slowly the gestation of a new perspective upon technology dawned for Ropohl, viz. that of the socio-technique, which manifested as a "trans-disciplinary synthesis" of an action system that relies both on human and technical function carriers (Ropohl, 1999: 67; 2009). Ropohl's *Theorie soziotechnischer Systeme* and a *Techniksoziologie* thus became a series of submissions which argue for technology to be understood as bearers of derived act-functions, not as autonomous act-bearers - it is still humans who [inter]act with technology to extract functionality. His purpose with this discourse is to lay bare the holistic connections between technology and society, to highlight the human intervention in the intertwining relationships, and to bring problems of social practices closer to a solution.

Ropohl (1997: 70) allows for an interesting perspective of the earlier development of his formulation of the socio-technical theory. Here he summarises his four perspectives of technical knowledge, i.e. technical know-how, functional rules, structural rules, and technological laws. He states subsequently that "There remains another type of knowledge not yet very common to engineering, but of crucial significance for coping with the present justification crisis of technical progress, and this is socio-technological understanding".

When he then proceeds to formulate his theory, Ropohl combines all his knowledge of General Systems Theory and his experience of technology in action into this new approach. Ropohl (1999: 66-67) throws further light on how the theory came together. He explains how an active entity is a system that acts; by transforming a starting situation into a final situation. Or, in the functional terms of systems theory, it can be described as a transformation of inputs into outputs dependent on specific internal states (including goals).

Skyttner (2001: 74) describes this sequence of input, process and output as the "open-loop system". For Ropohl, inputs, internal states, and outputs can be characterised as matter, energy, or information and they occur in space and time. System acting includes, above all, work and communication; hence the role of information. The fourth systems law, which is that a system can act on more than one level, leads Ropohl to specify that his socio-technical theory must be active at the micro, meso and macro-level, or then involving the individual, the organisation and the society, all which may be conceived as action systems in a functional sense. Combined, this conception allows for identification of subsystems active in any specific transformation process; it allows for identification of the transformation process itself in its role as execution system, as well as for identification of the coordination and the communication functions. Subsystems may be subdivided into sub-subsystems, taking over specific partial functions such as receiving, storing and processing.

From the above, the eventual composition of Ropohl's nine cell matrix becomes clear. But, as a concept forming part of a wider socio-technical theory, the nine cell matrix remains in this context confined within a wider theory which came about as a result of the extreme positions technological determinism and social determinism took at the time. The matrix cannot be found to feature in a more profound role in Ropohl's subsequent work. As a graphic depiction encapsulating his theory, the matrix seems to be a mere by-product, generated to demonstrate how General Systems Theory allows for graphical and symbolic depiction of complex concepts. At this stage of its development, it remains a mere concept – left behind as an artifact of a wider and larger discourse about the philosophy of technology. From here the matrix evolves, however, from concept to a theory displaying the attributes of a paradigm. In other words, from a concept which represents technological phenomena in society it is shown to evolve, because it attracts attention among academics and practitioners and slowly but increasingly is applied as a construct. Thanks to increased attention, deeper analysis and more application, as a construct, again, the functionality grid is shown to become associated with variables which make explanation of complex phenomena easier. It is seen to aid explanation and prediction of how technology behaves, and through further application and testing becomes recognised as a theory contesting for paradigm status.

From an ontological perspective, the nine cell matrix and its later manifestations as first the "nine-cell matrix for functional classification" and then as the functionality grid, immediately and almost intuitively appears as an instrument for understanding what technology is, and what it does. As a paradigm, the functionality grid stands in clear relation to all three ontological frameworks dealt with here. There are clear reflections in the theory of early Heideggerian elements and principles of technology, i.e. the essential nature of technology, as well as structure, order, control, flexibility and efficiency. Specifically, from a morphological perspective, the notion of structure and order as first order objectives in technology thought manifest very strongly in the functionality grid. As second order objectives, the notions of flexibility and efficiency in technology functioning are brought about by subsequent refinement of the theory. Demonstrating the relationship between action and output, and various categories of outcomes, present strong ontological foundations for an epistemology of technology, and create the intellectual toolset for generating technology knowledge and insight. This allows indeed for knowledge of the Heideggerian "being of what is" insofar it concerns technology.

In the language of Smuts' Holism, the picture of the whole system brought about by the functionality grid shows "inwardness of structure and function". Structure here represents the familiar systems-based sequence of input, transformation and output. Van Wyk (2008b: 6) puts this relationship in perspective, i.e. the essence of technology is functionality, but physical reality in the form of matter, energy and information (MEI) represents an inevitable structure and composition.

Reflecting upon Ropohl's use of the three-fold classification of MEI, Van Wyk (1979: 282) also explains how the so-called Zwick triangle, depicted in Figure 3.1 and representing the unity of these three substances, is derived from General Systems Theory.

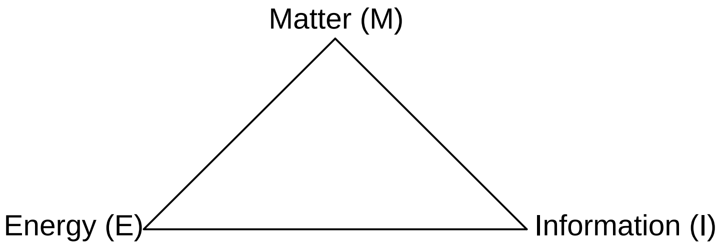


Figure 3.1: The Zwick triangle

Source: Van Wyk, 1979: 283.

Van Wyk (1984: 105) describes this unity as a fundamental and all embracing "technological trinity" encapsulating the entire spectrum of existence understood to be part of technology and technology thought. Van Wyk (2009a: 8) explains the unique role each of these elements of physical reality fulfills as input into any particular system. Matter has substance; energy performs work; and information conveys meaning.

Functionality manifests when these three physical substances are transformed by any one or a combination of processing, transporting and storing as types, or system elements, of manipulation. Specifically, processing involves receiving inputs of one kind and transforming them into outputs of another kind; transporting constitutes of receiving inputs and moving them a certain distance to another location before releasing them; and storing involves receiving inputs and holding them for a period before releasing them (2009a: 8). These system actions provide for deconstruction of all business operations, from the simplest to the most complex. The combination of three physical inputs and three transforming actions results in the nine cells representing the totality of transforming physical reality as they appear in the functionality grid. Roles of, and relationships between, the unit as a whole versus its parts become clear. As a totality, the functionality grid ultimately offers a comprehensive, coherent and concise view of the range, and reach of technology. It meets its final ontological obligation, which is to serve as a model for description of the essence of what technology is, and what it does, in the most holistic sense.

To conclude, the functionality grid as ontological expression has its roots in Ropohl's socio-technical theory as it was meant to reflect a new understanding of the relationship between technology and society, and as it was meant to depict the principles of General Systems Theory. That these principles reflected Smuts' Holism is not incidental. As shown by Zeleny, this came about as a result of the intrinsic character of the philosophy of Holism and the profound influence it was to have upon the General Systems Theory and indirectly then on Ropohl's socio-technical theory. Ropohl did not, however, develop the original matrix further. It is mainly American scholars who developed the original matrix and who now give context and substance to the initial ontological expression of the matrix. Thanks to this pioneering work, the original nine cell matrix is now postulated as a theory in its contemporary format as the functionality grid. It is postulated as a theory, because it shows epistemological substance and activity. Thanks to its ontological foundations, and thanks to its intrinsic vitality, the functionality grid now represents an episteme. It is now in a league where it is postulated to create and transact knowledge of technology. It is, therefore, appropriate to now examine the functionality grid's fit to the next layer of the paradigm template, i.e. that of epistemology.

3.3.3 Epistemological foundations

Guba (1990: 18) states a deeper philosophical objective for the epistemological layer in the paradigm template, i.e. to assess the relationship between the inquirer and the knowable. In the discussion about the paradigm template, the practical implications of this relationship were set out. Questions must be answered about whether the theory presents an identifiable body of knowledge, and whether it contributes to a body of knowledge together with its knowledge creating communities. The mechanism of how it does so must be investigated, together with the structure of its activities and the structure, logic and content of the body of knowledge. Finally, the integration of these elements and the synchronised nature of their combined effect must be investigated to establish whether they help present answers to existing problems, and whether they have the potential to solve future problems.

3.3.3.1 An epistemology of technology

From the digital archives of the *Society for Philosophy and Technology* much can be learned about the philosophical debates concerning the nature of technology, about the nature of the Philosophy of Technology as an independent discipline and about the nature of the differences between science and technology. The same applies for Durbin's (2006) work in seeking a synthesis for the discourse about the philosophy of technology. Judging from these archives, agreement of what an epistemology of technology is remains elusive. If Durbin (2006: 4-5) is read correctly, philosophers of technology endeavour to reach consensus on what constitutes genuine knowledge, as well as what its goals should be. Knowledge communities have always agreed that scientific knowledge is cumulative, and that knowledge is an enabling capacity. The difference appears to be about *how* knowledge becomes cumulative and *how* it is subsequently applied. According to Durbin (2006: 6), from "…among the earliest intellectuals calling themselves philosophers of technology there were many critics who were convinced that technology is, on balance, bad rather than good for our technological society". This brings the discussion back to the debate about the relationship between technology and society. Van Eijck and Claxton (2008) provide a contemporaneous perspective of the argument that technology should be seen as a knowledge field in its own right, separated from science, and they then introduce the notion of a techno-epistemology. This, again, relates back to the question of whether science and technology should be seen as separate, each earning its own merits as unique human endeavours – even if they are closely related.

For the aim and objectives of this study, a new bearing is therefore needed so as to remain on course. In his effort to formulate an epistemology of technology, Joseph Pitt, as quoted by Allchin (2000), gives some direction, if it is to be considered here that the aim with this study is not to investigate technology as a separate endeavour. Pitt suggests an epistemology of technology to first and foremost deal with questions about what can be known about a specific technology and its effects, and of what that knowledge consists – with the latter part of this question constituting of a typical ontological character. Furthermore, the role of knowledge communities should serve as a directive as well, especially so given the comparison by Peine (2008: 3) of knowledge creating communities as the constitution of paradigms. The task is now to apply the paradigm template and assess the epistemological merits of the functionality grid.

3.3.3.2 The functionality grid as an epistemological statement

According to Broens and De Vries (2003: 459), not much is written about the nature of knowledge of technology as a distinctive kind of knowledge, aside from a number of technology typologies. It is, therefore, necessary to assess whether the functionality grid improves upon this particular shortcoming. From the preceding analysis of its ontological foundations, the functionality grid appears to be more than a mere typology, or a simple taxonomy of technology. The initiatives listed below show how the functionality grid serves to bring conceptual structure to technology thought, and how this characteristic of the theory again creates knowledge and insight about technology and the broader technological landscape. These initiatives are as follows:

1. A first academic initiative to show how the functionality grid benefits analysis of complex technologies is credited to MIT, where Magee and De Weck (2004) have used functional

type as a central attribute for differentiation and classification of complex engineering systems. They indeed find functional type as the most useful attribute of complex engineering systems for differentiation and classification of such systems.

2. This first initiative was followed up by Koh and Magee (2006). They describe technological progress and specifically technological capability when they use functional classification to derive a set of functional performance metrics (Koh & Magee, 2006: 1063) for the Information Technology (IT) industry. With their focus on the Information operand, they define each functional operation, i.e. transformation, transportation and storage as it applies to the IT industry and they then allocate to each at least two functional performance metrics. For example, transformation of data is measured as calculations per second and calculations per second per unit cost. They find statistically significant differences in technological progress among the three functional operations, while differences between progress rates for different metrics and for different technological form factors within a functional category appear relatively small. Importantly, they empirically confirm how the wider and more systematic functional approach shows more stability for analysis of long-term technological progress and performance than device-specific analyses (Koh & Magee, 2006: 1073), in this instance demonstrated with information functionality.

   Koh and Magee (2008) extend their practice of choosing functional categories for analysis of technological progress to the energy operand. This enables them to compare technological progress in the IT and energy operands respectively. They find that IT manifests a significantly higher rate of progress in all three functional categories, and that the rate of progress for IT is greatest in transformation and least in transportation whereas for energy the rate of progress is greatest in transportation (Koh & Magee, 2008: 13).

3. The third initiative where the functionality grid serves as conceptual foundation is in STA. Van Wyk (2004b) offers a description and an explanation of STA and its constituent parts, which respectively are the characterisation and decomposition of technological entities; the classification of such entities; the tracking of technological trends; charting of technological potencies and profiling of societal and environmental preferences. Van Wyk (2000) uses STA to map and track medical technologies and shows how this analytical framework can be leveraged to promote technology literacy in organisations. Howey (2002) demonstrates how the Cascade model as part of STA can be modified for the analysis of computer software technologies, which have consistently posed an analysis problem because of their peculiar intangible nature. STA has been shaping academic courses in MOT, has offered its circle of adherents deeper insight and a more coherent understanding of the larger technological landscape, and has been serving as a tool for corporate technology road mapping.

4. The fourth initiative relates to the use of the functionality grid for charting technological frontiers, with Van Wyk and his Associates' Techno-trend Explorer's Manual (2008c) as the primary application. This manual consists, among others, of technology scans and assessments. It classifies technologies into the various classes presented by the functionality grid, and so helps to synthesise particular taxonomic results from among a multitude of competing technologies due for the market place, which again brings spontaneous insight to decision-makers into the nature of the fast-changing technological landscape.

5. The fifth initiative involves the use of the functionality grid for structuring academic courses, professional development workshops and technology edification programmes. With this initiative there have been clear signs that the functionality grid is gradually being accepted as an induction into technology for professions widely different from typical MOT practitioners, examples of which are investment professionals, portfolio managers and corporate directors.

These applications can be seen to involve a wider community of MOT practitioners, which is a key characteristic attributed to paradigms. Most importantly, however, these initiatives clearly show how the functionality grid from among contesting theories brings conceptual order and coherence to difficult conceptions of technology. This influence remains a common thread across all of these applications. The epistemological contribution of the functionality grid is indeed to serve as a universal structure towards technology thought. This has a direct and positive bearing upon knowledge of technology. Looking at the structure of the MOT body of knowledge proposed by Van Wyk (2008a) and depicted in Figure 1.1, the epistemological value of the functionality grid settles down at the centre of this structure, where knowledge of technology forms the basis of MOT. From the centre outwards, knowledge of complimentary topics rounds off the body of knowledge.

Van Wyk (2009a: 6) states that knowledge of technology as found in the centre of this epistemological structure can be divided into micro and macro aspects. The former focuses upon "*particularized knowledge*" (emphasis in the original) of specialist areas such as biotechnology, nanotechnology and engineering specialities. The latter covers macro, or holistic aspects of technological aggregations, such as the technological landscape and the technological frontier. To describe the comprehensive and all-inclusive nature of this focus, Van Wyk (2009a: 6) uses the term *technosphere*, and in the same context Kelly (2010: 11) uses the term *technium*, meant to designate the greater global and interconnected system of technology found in the cosmos.

3.3.4 Theoretical foundations

Ontology lives as a worldview and it guides epistemological activity, which again depends on theoretical endeavours for knowledge to be created. Method and practice are empirical and are found at the top of the pyramid. The dynamic nature of this ecosystem is symbolised by feedback loops, accordingly depicted in the paradigm template (Figure 2.3). This sequence thus started with an evaluation of the ontological foundations of the functionality grid, followed by an evaluation of its epistemological merits. The next step is therefore to determine how the functionality grid behaves as a contesting theory in MOT.

Theory fills a special and central niche in the Kuhn paradigms. The entire discourse of paradigm dynamics as beholder of scientific progress focuses upon the role of theories, upon how they compete and how some of them ascend to become paradigms. Looking from the perspective of the paradigm template, evaluation of theoretical merits involves the questions about the theories of the paradigm, the identification of a dominant theory, together with its substance, rules, symbolic generalisations and associated tools for easy formalisation. Evaluating the functionality grid as theory, the first question which arises is about its theoretical bona fides. An answer must be found as to why it appears to be a dominant theory in time of scientific crisis, in comparison to contesting theories, and whether indeed it presents the possibility and the potential to convert researchers and practitioners to its methods and practices as exemplar solution.

Given these questions, the next section presents first an overview of theory contestation within MOT, and then an evaluation of the functionality grid in terms of the template guidelines set out above.

3.3.4.1 A theory of technology

The participants in the discussion about the ontological foundation of technology also discuss epistemology and theory of technology, because they - philosophers of technology - see technology as a separate endeavour against science. In their approach, technology constitutes a paradigm on its own. This study follows a different approach, which involves a perspective upon theories from within the discipline of MOT. It assumes that MOT is an academic discipline within the endeavour of science, supporting the profession which represents it in practice. From this point of view, there is still much disagreement about a theory of technology and its role in relation to MOT. This can be ascribed to different world views of participants in the discussion.

Arthur (2009: 4) in the preface to his book titled *The Nature of Technology* declares that there is no overall theory of technology. But there are many contestants vying for this role. Callon, for example, suggests Techno-Economic Networks as a theory of technology (Green *et al*., 1999), while Bowonder and Miyake (2000) compare technology management to the management of knowledge ecosystems. Based on this assumption, they then develop a framework based on knowledge management and the ecosystem theory for an analysis of technology management issues. Dostal and Cloete (2002) introduce the biomatrix theory as a particular worldview to deal with technology complexity and to propose frameworks for its management. The biomatrix theory views the universe as a web of interacting systems, constituting three sub-webs namely that of nature (i.e. the naturosphere), of society (i.e. the sociosphere) and of technology (i.e. the technosphere). This approach provides frameworks and methods for problem solving across all three these dimensions of reality. It specifically signals the message that complex problems span different levels and dimensions, and hence require appropriate interventions at each level and within each dimension with the limited resources available within each level's constraints.

Lorenz and Palm (2004) use MEI to propose a theory of technology which involves human energy and the manifestation thereof. Bond (2003) first proposes a thought-provoking biological theory of technology, according to which reconciliation with nature is pursued. Continuing with this line of thought Bond (2006) subsequently expresses the need for a new paradigmatic framework for technology, described as the living systems paradigm. Feenberg (undated) cites instrumental and substantive theories as established theories of technology, from which he invokes his critical theory of technology, which opposes technology neutrality and technology determinism with a social-ontological world view; Feenberg (undated) sees technology not as the product of technical rationality, but as a combination of technical and social factors, in what he describes as "hermeneutic constructivism".

3.3.4.2 The functionality grid as contesting theory

This study assesses whether the functionality grid complies with the requirements of a paradigm. The theories introduced above prove that there is in fact theory contestation within MOT, and it shows that the discipline of MOT experiences paradigm activity outside the normal mode of puzzle solving. But whereas this first category of theories is, generally speaking, more philosophically inclined, a next category proves a more formidable contest to the functionality grid. Theories in this category compete directly with the functionality grid in terms of their application. Van Wyk, Karschnia and Olson (2008) give an overview of the following three contesting theories:

1. The engineering model is promoted by engineering disciplines such as civil engineering, mechanical engineering, electrical engineering, electronic engineering, etc. to describe technology in accordance with the respective technical modes of these disciplines. While the model is comprehensive, it is neither coherent nor concise, because it is not branch agnostic. So, the civil engineer may view the concept of networks from an entirely different perspective

than would the electronic or industrial engineer. The engineering model does not offer an overarching theoretical framework for MOT.

2. The thematic model uses scientifically-based themes to describe various technological focus areas. Familiar and widely publicised themes are information and communication technologies, medical technologies, transport technologies and military technologies. From an international technology governance perspective, this model is also very popular and is used by several policy-making agencies such as the National Science Foundation (NSF) in the USA, and the United Nations Industrial Development Organization (UNIDO), with a particular focus on high profile technologies such as nano-technologies, bio-technologies and nuclear technologies. Of course, from a MOT point of view, the thematic model has the same fundamental drawbacks as the engineering model. This model does not have inner boundaries for demarcation of these themes when compared to each other, nor does it have outer boundaries for delineation of the technology totality as does the functionality grid.

3. The economic model uses economic categories such as the International Standard Industrial Classification (ISIC), or the North American Industrial Classification System (NAICS) to describe various technological areas. In the case of ISIC it differentiates between 20 economic sectors, such as agriculture; forestry and fishing; mining and quarrying; manufacturing; transportation, and so forth. The economic model is complex and does not match the conciseness of the functionality grid. Van Wyk *et al*. (2008: 63) describe it as cumbersome, disconnected from technology realities and not suitable for strategic technology analysis, even if it has the advantage of a formal and bounded structure derived from economics.

These theories all have niche roles to fill. They do not however match the systematic, concise and coherent perspective of the technological landscape as effectively as does the functionality grid. Furthermore, they do not have the range of practical applications in MOT as does the functionality grid. Kuhn (1970a: 95) states that a new theory does not have to conflict with its predecessors, and that it may deal with phenomena in a manner not seen before. It may be a higher level theory than its contestants. When gauged against the direct measures proposed by the paradigm template for theory, the functionality grid indeed stands out well above its competition. As a contesting theory the functionality grid contains a firm set of rules to guide problem solving. This is proved by the several examples listed of where the functionality grid is demonstrated as epistemologically active. Among competing theories in MOT, the functionality grid serves, furthermore, as a trendsetter in the easy and accessible manner it helps to formalise general technology principles. Its simple symbolic generalisation, supported by the MEI equation of the technological trinity, allows for intuitive understanding of a complex and dynamic whole when technologies are examined.

Against its competition, the functionality grid stands out in terms of ontological, epistemological and theoretical terms. For the question as to whether the functionality grid presents the possibility and the potential to convert researchers and practitioners of pre-paradigm or incumbent paradigm science to the new paradigm, the answer is found in an expanded number of applications by MOT practitioners. Closer inspection of this dimension of the functionality grid follows next.

3.3.5 Methodologies and practices

3.3.5.1 Methodologies and practices in paradigms

Kuhn (1970a: 46) writes that a "…new theory is always announced with applications…without them it would not be even a candidate for acceptance". Method forms part of the paradigm commitment and is to Kuhn as much a part of the paradigm as is the case with its other components. Accordingly, TSoSR is richly illustrated with examples of paradigms in action where their methods are described as incumbent exemplary solutions. Method ultimately solves society's problems, and it helps to convert adherents for the paradigm by its results. But Kuhn is on record that paradigms need not, and cannot solve all problems that come across its road. It is not a panacea.

The question now is whether the functionality grid contains a toolset of methodologies and practices which reflect paradigm dynamics. Confirmation is needed that these methods and practices are widely applied, and that that they as set standards appear to represent exemplary solutions to problems in MOT. Finally, support by conceptual artefacts of note is looked for as well.

3.3.5.2 The functionality grid as exemplary solution

The functionality grid does in fact not only attract more academic attention, it is already used in practice to promote technological literacy among MOT practitioners. The following examples serve to prove its increased application as exemplary solution:

1. The South African Department of Science and Technology used the functionality grid in its foresight report to analyse technical trends and their relationship to socio-economic needs as these forces impact upon security in South Africa (DST, undated).

2. The South African division of a global telecommunications firm holds a firm belief that the functionality grid helps to explain technological progress and uses the model to order and

structure technologies identified as being of strategic importance to its mission. The local director of strategy accordingly plans to employ the theory more aggressively.

3. The functionality grid also serves in the classroom at the University of Stellenbosch Business School (USB) as a systematic framework for technology analyses. Plans are afoot to use the theory more widely, especially in combination with STA.

4. Confirming the versatile nature of the functionality grid, Dr. George Biltz (Biltz, 2009) continues to use this theory as a way to consistently approach, analyse and describe physiological phenomena in his physiology classes at the University of Minnesota in the USA. Biltz writes that he continues to use the “tool” for both exploring conceptual questions and for teaching Physiology. He recommends this “functional framework” as a means towards consistent observation across all levels of description of his subject field.

5. To financial analysts and other MOT practitioners, a primary avenue for overviews of the latest technologies due for the market place is Van Wyk’s (2008c) *Technoscan® Newsbrief*s. These technology newsbriefs consist of monthly newsletters to subscribers, and every edition introduces a new technology appearing on the horizon. Newsbriefs always have their content filtered to ensure that in accordance with the functionality grid they focus on the pre output that best describes the technology under discussion; that they focus on the most appropriate technology hierarchy; and that they clarify the role of the technology under review in relation to other technologies if higher up in the technology hierarchy. Typically, the news-brief focuses on a) important, but unmet technology needs; b) rapid technological advances; c) scientific research backing up such technological advances; d) growing markets for the technology presented; e) perceived environmental benefits and drawbacks; f) social preferences as these may apply, and g) the presence or absence of political support, where relevant. They therefore present a bird’s eye view of technology progress and potential.

6. Anecdotal evidence exists of the use of the functionality grid for planning of counter-insurgency platforms in the USA Marine Corps.

All of the above applications flow directly from the paradigm manifestation process which the functionality grid demonstrates as contesting theory, i.e. practitioners and academics apply the theory and in most instances report through their professional forums about the processes they followed and the results they achieved. This helps to frame the functionality grid as an exemplary solution, or best practice, which is accessible to MOT practitioners so as to help solve practical problems. The theory continues to grow in stature and its application is increasingly recommended in practice and in academia. With these applications the functionality grid helps to generate knowledge of and insight into technology, and it helps MOT practitioners to capture technology-based innovation opportunities, which remain the essence of this profession.

The functionality grid is distinguished from a range of MOT tools and practices by its paradigm merits. It is, however, a theory in contestation with other theories. This reality is demonstrated by the fact that other toolsets also enjoy attention in the MOT community. Examples are Brady, Rush, Hobday, Davies, Probert and Banerjee (1997), Phaal, Farrukh and Probert (2006), Levin and Barnard (2008:1-2) and Brent and Pretorius (2008). Unfortunately, seen from the paradigm template perspective, the first three contributions demonstrate how a very relevant and deserving discussion about MOT tools and routines fails to elevate itself to the paradigm discourse. The discussion remains at the level of tools and routines. These tools are tools for puzzle solvers in Kuhn's language. They are not positioned as paradigms, because as tools and routines they do not have the supporting scaffolds of paradigms. They remain only technical solutions and procedures discussed in a community of practitioners. Against this, Brent and Pretorius introduce a conceptual framework of technology management knowledge, together with associated tools and methodologies towards sustainable development. This appears a timely contribution which offers further competition to the functionality grid. The task remains now for these tools and methods to be understood and be promoted in Kuhnian terms, because this may change the dynamics of the scientific crisis in MOT, and in the process may further benefit MOT.

3.3.6 Evaluation of fit – concluding thoughts

The evaluation of the functionality grid's fit to the paradigm template is not an exact science. The paradigm template is a ready-made construct and the evaluation is an academic exercise based on a literature research. All told, this analysis confirms the paradigmatic dynamism in MOT. It shows how in comparison to contesting theories, methods and practices, the functionality grid has grown in stature from a mere concept to a theory. The most positive observation in this regard is that the theory is based on very firm ontological ground, from where it contributes to an expanding and conceptually structured epistemology for the MOT body of knowledge. From this chapter, the functionality grid systematically proves to meet with the theoretical requirements of a paradigm.

When viewed via Kuhnian lenses, MOT can be described as a discipline in crisis. The crisis is of a theoretical nature, as is affirmed in Chapter 1. The discipline lacks a scientific paradigm, according to Van Wyk (2002: 15; 2004b: 10); a view confirmed by Lochner (2009), who finds that MOT is a discipline in pre-paradigmatic phase. But with the paradigm template evaluation completed, MOT also shows symptoms of Kuhn's so-called normal science. So, on the one hand, the MOT community behaves like pre-paradigm communities, all competing for dominance with their contesting ideas. But on the other hand, the astute observer, looking at MOT via the Kuhnian lenses, may claim that MOT practitioners are simply busy with normal science, described by Kuhn as “puzzle solving”. They use well known methodologies and practices to solve problems and typically they would anticipate as a given the results of their endeavours. They know their frameworks and they apply these frameworks without questioning them. Leaving aside the fact that the functionality grid complies with the theoretical requirements of a paradigm for MOT, to these practitioners there is in fact not a crisis in the discipline. However, thanks to the paradigm template, theory contestation is demonstrated in MOT, and the functionality grid can be confirmed to comply with the theoretical requirements of a paradigm in the discipline.

According to Kuhn (1970a: 7), the assimilation of a new paradigm into a scientific community requires reconstruction of prior theory and re-evaluation of prior facts by many role players, which in effect makes for the revolutionary activity central to paradigm formation, paradigm competition and paradigm shift. The problem statement in Chapter 1 describes the nature of the crisis in MOT. It also describes the anomaly of a society which lacks technological literacy in a world characterised by technology omnipresence. This is an anomaly of significant magnitude, with potentially severe economic consequences. And it is counter-intuitive to the expectations of these otherwise widely read and well-educated societies. It is counter-intuitive to theories of knowledge transfer and adoption as well. The questions have to be asked: Why, for instance, can leading nations clone a gene and excel in space exploration, but as civil and corporate societies they lack technological literacy? Why can this problem not be solved by MOT? If the incumbent paradigm cannot solve the problems of the scientific community, then slowly and gradually individuals will become aware of anomaly and subsequent crisis in their discipline. Awareness of a paradigm will lead MOT practitioners to start comparing and test solutions between the rival theories. In accordance with Kuhn’s (1970a: 144) diagnosis, the functionality grid indeed has at first emerged only in the minds of those few MOT practitioners who have been exposed to the functionality grid through academic programmes, industry conferences and associated literature. But these individuals have had their attention focused intensely upon the crisis-provoking problem within the normal science endeavour; and mostly they were not bounded or constrained by “puzzle solving” rules in those organisations and communities where they went forth and applied the theory.

As stated earlier, the crisis and the revolution observed is not a linear process and no immediate rejection of the *status quo* is to be anticipated, even if the serious problems described in this study persist. The solution, of course, is to first understand that social science, and for that matter economic and management sciences as well, would not exactly fit onto the Kuhnian paradigm template. The anomaly must first be allowed to worsen, the merits of the paradigm as exemplary solution must first be demonstrated through its adherents before it is to be gradually and later more generally accepted. If it appears viable, the few adherents of the functionality grid may grow into many among the global community of MOT practitioners.

3.5 CONCLUSION

This chapter introduces the functionality grid and describes its evolution from a concept to a contesting theory in MOT. The paradigm template guides an evaluation of the theoretical requirements of the functionality grid as a paradigm for MOT. The results show that this theory contains all the necessary theoretical elements of a paradigm. Especially encouraging is the fact that the functionality grid is based on very firm ontological foundations, and that it makes a timely epistemological contribution to the recently proposed MOT body of knowledge. The functionality grid is also shown to have a firm and systematic conceptual structure, with simple and easy rules for applications, and accessible symbols which make understanding and learning easy. Following from the template evaluation, the last section of this chapter offers a view of MOT as a discipline in crisis. This view helps to give perspective of the role of the functionality grid in this discipline, specifically when conceived of as a paradigm which serves as exemplary solution. This chapter concludes the assessment of the theoretical requirements of the functionality grid as paradigm. Now that this theory is known to comply with the theoretical requirements of a paradigm, the next chapter assesses whether the functionality grid complies with the empirical requirements of a paradigm.

CHAPTER 4
ASSESSMENT OF PRACTICAL MERITS:
SEMI-STRUCTURED INTERVIEWS AND CONTROLLED EXPERIMENTS

4.1 INTRODUCTION

From the preceding analysis, it becomes clear that the functionality grid complies with the theoretical requirements of a paradigm. Does the functionality grid have the merits to promote technological literacy in practice? Evidence consequently needs to be sought to underpin the theoretical observations described earlier. A historical example of the same kind of endeavour can be found in the creation of a biological taxonomy by Linnaeus in the 17th century. Linnaeus demonstrated the merits of his taxonomy by assigning a classification task to two colleagues. They were asked to categorise the plants in a particular garden. One colleague, to be called the experimental candidate, was taught Linnaeus's system, the other, the control candidate, was not. It must be borne in mind that, at that stage, there was no universally accepted system of classification. It is said that most biological inventories were dealt with alphabetically. Practitioners were faced with problems of linguistic differences. Classification therefore involved two steps, categorisation and allocation. In the Linnaeus experiment the first colleague finished his task in a fraction of the time that it took the second. Linnaeus was able to offer this as evidence that his system had practical merit. In the case of the functionality grid, a simple experimental proof of this kind would be much more difficult. The functionality grid was not intended as an unambiguous taxonomy, it was a concept intended to pave the way for a convenient understanding of socio-technical systems. Later it was elevated to a central format to enhance the skill of MOT practitioners. To judge how effectively the functionality grid does this, it is necessary to determine a hierarchy of outcomes that exposure to the functionality grid is supposed to encourage. To this end, this chapter deals first with the research design. It next presents a complete description of how a triangulated data model is systematically constructed and implemented. This data model consists of, respectively, semi-structured interviews, a quantitative experiment and a dual-nature experiment. From this follows data description and analysis. The final section offers a deeper analysis of the empirical findings.

4.2 THE RESEARCH DESIGN

4.2.1 The basic principles

Christensen (1997: 343) describes the research design as a plan specifying how data are to be collected for the research and how unwanted variation is to be controlled. Welman and Kruger

(2001: 46) define the research design as "…the plan according to which we obtain research participants (subjects) and collect information from them". Bryman and Bell (2007: 40) describe the research design as a framework for the collection and analysis of data. According to the latter, the choice of the research design reflects the priority given by the research to a range of factors, among which are the causal connections between variables, generalisation, understanding of behaviour, as well as temporal understanding of social phenomena and their interrelationships.

Christensen (1997: 317) states three criteria to be met by a "true" research design. The first involves the measure to which the design tests the hypothesis and hence answers the research questions. The researcher must envisage the technical voyage towards conclusions to be forthcoming via the research design. From this follows the question of whether the research conclusions indeed present answers to the research questions. The second measure involves internal validity and pursues control of extraneous variables. More specifically, the effect to be observed must be attributed to the independent variable in the research design, and not to an extraneous variable which involves a rival hypothesis. When this measure is met, the research complies with the principle of internal validity. The third measure of a true research design involves external validity, which involves the question of whether the research results can be generalised to situations outside the scope of the study. However, according to Christensen (1997: 320), these three criteria represent the ideal, which for all practical purposes cannot be achieved in equal measures. This proviso applies especially to social science. For this reason, basic research focuses on internal validity, while applied research gives equal emphasis to both internal and external validity.

From a strictly social science perspective, Denscombe (2010: 99) describes three functions of a "good" research design. First, it depicts the various components of the scientific investigation. Second, it clarifies the relationship between the research propositions and the research strategy. Third, it shows how the various key components of the study link up. Ultimately, the cornerstones for choosing a design, apart from fitness for purposes, feasibility and costs, are validity and reliability. Denscombe means that validity and reliability must be understood here as transcending their traditional application in the logical positivist tradition, so that their application also enjoys prominence and engenders confidence in social science. In this context, validity involves the quality of data, and reliability involves quality of methods (Denscombe, 2010: 106).

4.2.2 Practical research objectives

The focus now shifts to the development of a research design with its associated methodologies for the evaluation of the empirical merits of the functionality grid. Broadly seen, the research design pursues a hierarchy of outcomes which is to progressively demonstrate how the functionality grid complies with Kuhn's empirical requirements for paradigms. This hierarchy of outcomes is depicted below:

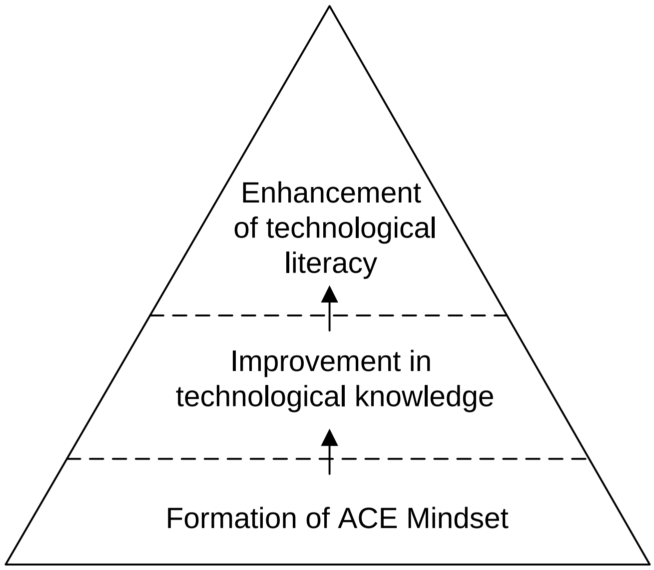


Figure 4.1: The hierarchy of outcomes

Source: Author's own, 2011.

When introduced to the functionality grid for the first time, it leaves upon the inquisitive and attentive mind an impression of structure, order, coherence and comprehensiveness. The first outcome, therefore, involves an assessment of whether the functionality grid makes a deep and lasting impact upon MOT practitioners' mindset insofar it concerns technology understanding and exploration. The goal is to assess how the functionality grid helps MOT practitioners in developing a wider and holistic view of the technology landscape, and how their mindsets accordingly develop in their work of technology exploration. Van Wyk (2009a: 2) describes this mindset with the acronym of ACE, standing respectively for a) *Anticipatory*, in other words thinking ahead through the many and confusing technology developments which appear on the technology intelligence radar screen; b) *Comprehensive*, in other words, forming a panoramic overview of the possible technological pathways; and c) *Engaged*, in other words, pursuing technological potency with enthusiasm and vigour.

The second outcome involves finding and documenting evidence of whether exposure to the functionality grid leads to an improvement in MOT practitioners' technological knowledge. If the functionality grid does indeed leave an impression upon the mind of the MOT practitioner, and if it becomes clear that MOT practitioners find it easier to understand and explore technology thanks to the new insights gained from this theory, it is incumbent upon this study to further assess whether this theory would indeed lead to an improvement in technological knowledge.

As stated before, technological knowledge serves as the foundation for technological literacy. With the above foundations in place, the third and final outcome involves enhanced technological literacy.

4.2.3 A multi-method approach

The threefold nature of the hierarchy of outcomes suggests that a multi-method research method would be the most suitable approach given the post-positivistic nature of this study. Brewer and Hunter (2006: 1) see in multi-method research many opportunities for cross-validation and cross-fertilisation of research procedures, findings and theories. To them, single method studies are imperfect because they leave more opportunity for untested rival hypotheses, or for alternative interpretations of the data at hand. Multi-method allows for a combination of methods to gain individual strengths and to compensate for weaknesses in each of the individual approaches which make up the collective.

The process that follows from the multi-method approach is known as triangulation. According to Bryman and Bell (2007: 412), triangulation involves the employment of more than one source of data in social science research. They describe how the principle of triangulation is derived from the military industry, where its application involves multiple sets of coordinates triangulated to determine the exact position of an object of interest. Initially meant to be a measure in support of quantitative research strategies, triangulation now also supports qualitative research and is very appropriate for application in an “across research strategies” approach as is the case with this study. For Brewer and Hunter (2006: 4), “triangulated measurement” endeavours to locate and identify the values of a phenomenon more accurately by sighting in on it from different methodological viewpoints. The main benefit of this manner of doing research is, according to Brewer and Hunter (2006: 64), to be found in data diversity and quality, and not in quantity.

Brewer and Hunter (2006) guide the researcher in selecting the most appropriate methods from among a multiple possibilities. The priorities for this research are to use semi-structured interviews, a formal experimental design and a dual-nature experiment to progressively pursue the hierarchy of outcomes earlier described.

4.3 THE SEMI-STRUCTURED INTERVIEWS

4.3.1 Preparation

A series of interviews were conducted with MOT practitioners who were familiar with the functionality grid and were known to use the functionality grid in their professional lives. A sample of five practitioners was identified. The methodology employed was to follow a semi-structured approach. The semi-structured interview is less formal than a strictly structured interview. It allows the researcher to capture unanticipated insights. It uses open-ended questions, the sequence of which can vary. It allows two-way communication, which creates opportunities for reasons to answers to become part of the discourse. Not all questions are pre-designed and phrased. Some questions are created during the interviews, allowing both the researcher and the person being interviewed the flexibility to probe for details or discuss issues (Bryman & Bell, 2007: 213; Harrison, 2009: 336).

The research question to examine with the semi-structured interviews is whether the functionality grid at first makes a positive and lasting impact upon MOT practitioners' mindset insofar it concerns technology understanding and exploration. Hence the intent of this set of interviews to find out how these MOT practitioners have developed their impressions of the functionality grid, and how this affected their professional mindsets. Descriptions of thoughts are required. Confirmation of epistemological benefits is sought. Empirical confirmation of how the functionality grid works in practice as a paradigm is pursued. The answers to this question will help to determine the vitality and viability of the functionality grid as perceived by MOT practitioners.

The interview structure which gestated from the above reasoning appears in Appendix 1. This structure is designed to meet the general character of a semi-structured interview. At the same time, it allows for a logical progression of the discussion from the general to the specific. First on the agenda is an introduction by the interviewer about the general nature of technology and then follows a short introduction about the role of exemplary solutions such as STA and the functionality grid within the discipline of MOT. Although it is an open agenda, the interactive section of the interview structure focuses specifically upon the impact of the functionality grid upon the mindset of the MOT practitioner, and the potential it has to serve as an aid in technology exploration. A final point on the agenda allows for a discussion about perspectives, hindsight and reminiscences. The structure remains open however, allows for discussions to naturally evolve and for thoughts and impressions about the functionality grid to be spontaneously presented by the interviewees.

4.3.2 Implementation

The sample of interviewees consisted of five persons. The first four were interviewed personally, while the fifth was interviewed on-line. All of them had university degrees. The first four were MBA graduates.

The first interviewee is a university lecturer at the USB, Cape Town, South Africa. He is qualified as an electrical engineer, teaches and consults on ICT, has an interest in how ICT and MOT combine, and does MOT analysis with write ups for the Institute of Futures Research at the same university. A second interviewee is a retired vice-admiral from the South African Navy, where he was involved in technology analysis. He now manages a marine training academy in Cape Town. A third interviewee is a Cape Town based director for group strategy and research at a multinational mobile telecommunications company. The fourth interviewee is a marketing director for a startup company in the recycling industry, located in Cape Town. The fifth and final interviewee is a lecturer in Kinesiology, Human Physiology, and Exercise Physiology at the School of Kinesiology, University of Minnesota, USA. His, strictly spoken, was not an interview, because the interaction took place via email.

A sixth potential interviewee is a retired general from the South African Defence Force who served as the convener of committee which compiled a foresight report for the South African Department of Science and Technology. This report describes the application of the functionality grid in an analysis of technical trends and their relationship to socio-economic needs as these forces affect security in South Africa. The general never replied upon the formal email request for an interview, appended as Appendix 2, but he explained in a telephonic discussion with a facilitator that he was indeed only the convener of the working committee which applied the functionality grid in its analysis, and that he did not have the knowledge to sensibly participate in a discussion about the theory. His committee's findings are however published in a formal report which is referenced as a practical application of the functionality grid.

Given the fact that their diaries were expected to be full, the process to establish email contact with these professionals started during January 2010. First on the list was the interview with the university lecturer, given his position at the same business school as the author of this research report. This interview took place on 1 March 2010. Scheduling the second interview with the retired navy officer posed more of a challenge, as can be seen from the email interchange between the author and the interviewee, attached as Appendix 3. In the end, this interview happened on 9 March 2010. The most challenging appointment to schedule was with the third interviewee. At first, her contact details were difficult to trace; and secondly, given her diary and the nature of her work, all liaison after the initial contact took place via her personal assistant. When the author finally succeeded in tracing and contacting her, she did however immediately agree to the request for an interview, which took place on 23 March 2010. Her response in this regard is attached as Appendix 4. The fourth candidate came to the fore much later, during October 2010, when as a voluntary participant in the dual-nature experiment he informed the author that he was using the functionality grid in practice. Upon request, he immediately agreed to an interview which was held on 20 October 2010. A final submission is the email liaison with the lecturer at the University of Minnesota, which took place during November 2010. The request for an exchange is appended as Appendix 5.

As can be seen from the above, completing the full set of interviews for all practical purposes took the full 2010 calendar year. With two exceptions, tracing the interviewees, establishing contact and agreeing to the principle of cooperation required most effort. The interviews themselves, given their predetermined semi-structured nature, all took place in a cooperative spirit, with substantive inputs forthcoming from all the interviewees. Typically the sequence of these interviews was for a general opening to be followed by an introduction of the interview structure, along which the discussions then proceeded. In every instance, the interviewees were prepared to constructively and critically share their impressions and experiences of the functionality grid and where relevant their plans to use this theory in future. The average duration of these interviews was 90 minutes and with the exception of the email exchange with the lecturer in the USA, the discussions in all four cases were wide ranging and covered several topics associated with MOT and associated management practices. All the interviewees agreed to the request for the exchanges to be tape recorded for data transcription, validation and back-up purposes. The semi-structured and semi-qualitative nature of this exercise opened the agenda, and introduced more avenues for future exploration. The results of the four interviews were cryptically transcribed from the tape recordings and associated notes, and are appended as Appendix 6. The response received from the fifth interviewee in the USA is appended as Appendix 7.

4.3.3 Description and analysis of the interview data

The purpose of the interviews was to find out how the functionality grid evolved in the minds of the interviewees to eventually be conceived as a useful theory in technology understanding and exploration. The first guideline in the semi-structured interview structure, to lead the discussion towards answers upon the research question, was the discussion about the mindset change brought about by the exposure to the functionality grid. The researcher needed to find out how the introduction happened, what the background was, what the qualifications and academic or professional involvement of the interviewees were and how it came about that the interviewees were attuned to, or receptive for, this mindset change. These perspectives are encapsulated in Points 2 and 3 on the interview structure as appended in Appendix 1.

The former navy officer and the marketing director in the recycling business got introduced to the theory during lectures about STA. The electrical engineer turned university lecturer read a book in which STA features prominently, and the executive at the telecoms company first attended a professional development seminar on STA and then hired a consultant to cover the material as part of an in-house strategic planning exercise. The medical doctor turned university lecturer got introduced to the functionality grid at the University of Minnesota.

All interviewees were unanimous about experiencing a significant change in mindset. The first interviewee used the expression “a light went on”. He reported having to read the book more than once to get to a more complete understanding of how to apply the functionality grid. The third interviewee also reported a gradual growth in insight. In contrast to the measured pace in understanding of these interviewees, the fourth interviewee found the functionality grid immediately applicable. For several years, he had been looking for a simple model for technological exploration. During one presentation on STA he immediately recognised the value of the functionality grid as having a “neutral language” and “without the complexities of physics and mathematics”. The fifth interviewee reported a different way of grasping medical technology and mentioned the benefits in using the format of the functionality grid to develop a common framework for describing physiology, pathology and procedure. He envisaged improved skill in organising medical knowledge.

The second guideline formulated to help search for answers to the research question of how the functionality grid at an intellectual level evolved to become conceived as a useful theory in technology understanding and exploration, was about the outcome of the mindset change which the interviewees have had. This guideline is encapsulated in the two questions about the theory as a toolset for technology exploration and the question about outcomes and perspectives (points 4 and 5 on the interview structure). This second guideline pursues answers of how the mindset change in MOT practitioners has affected practical reality insofar it concerns technology understanding and exploration. The academic perspective of the first guideline is followed up by a practical perspective. The interviewees all were practicing professionals and can be seen to fit the earlier description of MOT practitioners. Even the medical doctor turned lecturer consults at a major international company which among others specialises in technologies for medical diagnostics and healing. With the exception of the retired navy officer, three of the remaining four interviewees, after their introduction to the functionality grid, resolved to use the theory as toolset in applications such as technology classes, technology exploration and technology business proposals. Their roads have been different to this stage. Some took longer than others. Some have been more critical than others. The functionality grid serves as framework in write-ups of technology futures to business executives, as framework for systematic structuring of technology strategies in the telecoms industry, as model in business proposals for recycling and as framework for analysis in physiology. Generally, these applications appear to have been important endeavours with potentially wide-ranging impact for the technology investment strategies of the communities of stakeholders which may have been exposed to the impact of these applications.

Even if adherents, there is critique against the theory from the interviewees as well. These points of critique range from the view that a single exposure to the theory will not be useful and that it should not be seen as a panacea for practical MOT problems; to the view that a champion is required to drive its application in the corporate technology investment strategy, and ends with at least two proposals for the theory to be expanded so as to include time as an additional operand to

MEI. These points of critique are most welcome, because they help the researcher to develop a more rounded picture of the theory under investigation. They offer new vantage points, and new leads for future research. They do not, however, refute the available evidence supporting the fact that the functionality grid makes a positive and lasting impact upon MOT practitioners' mindset insofar it concerns technology understanding and exploration.

From the personal interviews it is possible to draw the following conclusions regarding the hierarchy of outcomes. First, there is consistent evidence that knowledge of the functionality grid causes a significant impact on the mindset of participants. All interviewees were unanimous on this point. In the case of three interviewees there is also evidence of the emergence of an ACE mindset. Second, participants consistently report a discernible and significant improvement in technological knowledge. Third, it was not possible to reach a clear conclusion about increased technological literacy, as this was not part of the experimental design for the first test. However, there was evidence of the functionality grid serving as an exemplar for theoretical refinement in other academic fields, in this case the field of medical diagnosis and healing. Finally, while establishing the sample of interviewees, the author found evidence of the use of the functionality grid by practitioners as "a matter of course" but without any explicit awareness of its history or unique qualities. For them it had entered into everyday use as a natural and logical tool. From the point of view of this dissertation, and harking back to the discussion on the theoretical validity of the paradigm, it represents an indication of paradigm ascension.

4.4 THE QUANTITATIVE EXPERIMENT

4.4.1 Introduction

The set of interviews is limited in scope, and more evidence is required that the functionality grid complies with the empirical requirements of a paradigm. A more stringent test of the empirical merits of the functionality grid was required. Given the specific nature of this study, the best response upon these imperatives is a laboratory-like experiment. The following section therefore offers a full elaboration of the design and implementation of this experiment. An important aid in this process is the implementation of a pilot study in order to test the assumptions, variables, techniques and experimental material of the main experiment. The sequence of this section therefore deals first with all the design considerations of the main experiment, and then demonstrates how these considerations are tested in the pilot study, before it proceeds with a description of the development of the variables and the subsequent implementation of the main experiment. The final section concludes with a description and analysis of the data generated by the main experiment.

4.4.2 Design considerations

4.4.2.1 Laboratory-like versus field experiments

Sarafino (2005: 53) points out that the research setting holds important implications for the research strategy and associated methods. Laboratory research is typically associated with a high degree of control, with participants knowing that they are being tested. Laboratory-like settings may in fact be any setting allowing for a high degree of control over those present, over the data collection mechanism and over participant action during the experiment. Against this, Sarafino (2005: 53) describes field research as occurring in a real-life setting, with participants often not aware that they are being tested. Bernard (2000: 125) only refers to field experiments as experiments conducted outside formal laboratories. The best approach is therefore to distinguish between laboratory experiments as taking place in formal laboratories or in laboratory-like settings, versus field experiments. For the purpose of this study, the degree of control remains the distinctive factor, with a laboratory-like setting selected as the preferred approach.

True experiments of any kind are seldom found in business and management research, according to Bryman and Bell (2007: 44), because they are difficult to conduct in a manner complying with the requirements for control. The requirement for the manipulation of the dependent variable is seen as adding further complexity to the research design as well. In spite of these difficulties, Handfield and Melnyk (1998: 325) recommend experimentation as data collection method for instances where theories are developed, tested, refined or extended. When experimental designs are then indeed applied, the results are held as a benchmark against non-experimental research, because of the confidence in the robustness and trustworthiness of findings about causality forthcoming from these experiments, according to Bryman and Bell (2007: 44). This stems from the tendency of true experiments to offer strong internal validity.

Christensen (1997: 77) defines the experimental research approach as "…the technique designed to ferret out cause-and-effect relationships". This technique helps with the identification, isolation and observation of causal relationships between variables, because it provides for the manipulation of one or more variables under controlled conditions. Christensen (1997: 81) explains how cause as reason for observed changes in the dependent variable has been the subject of endless debates, and how Popper's falsificationist position means that a cause of an observed effect can never be confirmed even after several successful interventions. The benefits, however, of experimentation if carefully planned and conducted, hold much more potential than the sum conclusions of these debates.

The first benefit of experimentation is the strength with which causal relationships can be inferred. A second is the ability to manipulate precisely a variable of the researcher's choice. A third and final benefit is usefulness, with several examples of experimental results which have stood the test of time, especially insofar it generated solutions to problems. However, Christensen (1997: 88) does also mention the disadvantages of experimentation. These include the artificial and sterile nature of most experiments. Problems to properly design experiments, and the time it consumes are also among the disadvantages. A final problem is the critique that experiments are inadequate as method of scientific enquiry into human behaviour, especially given their manipulation of humans as “mechanistic objects”. Whereas the first is a matter of operationalisation, the second criticism indeed also proves valid for this research especially insofar it concerns refinement of design and the time it took from concept to operationalisation and completion. The third criticism is adequately accommodated to the extent that this study remains set upon the road of Post-positivism. It furthermore remains carefully within the parameters of an ethically responsible research approach.

This study embodies two controlled experiments conducted in laboratory-liked settings. These experiments are justified not only by their technical merits as explained above; they are also motivated by the intrinsic nature of this study, which is an exercise in basic research to promote theoretical field formation in the discipline of MOT, and so to help expand and anchor the theoretical basis of the discipline. By its very nature as contesting theory, the functionality grid acts as an intervention at the ontological, epistemological, theoretical and practical levels. It follows logically that experimentation offers the best technical mechanism to continue evaluation whether this theory complies with the empirical requirements of a paradigm.

Of the two experiments planned for this study, the first to follow is the main experiment which involves a pretest posttest design. This experiment involves a quantitative exercise where causal relationships are subjected to an appropriate statistical test. The second is a smaller dual-nature experiment which combines a formal experimental design and selected techniques from the qualitative tradition. These experiments are each fully described and explained in the next section.

4.4.2.2 A hypothesis testing deductive method

The most appropriate research approach to conduct the test for causal relationship is that of a hypothesis testing deductive approach, depicted in Figure 4.2.

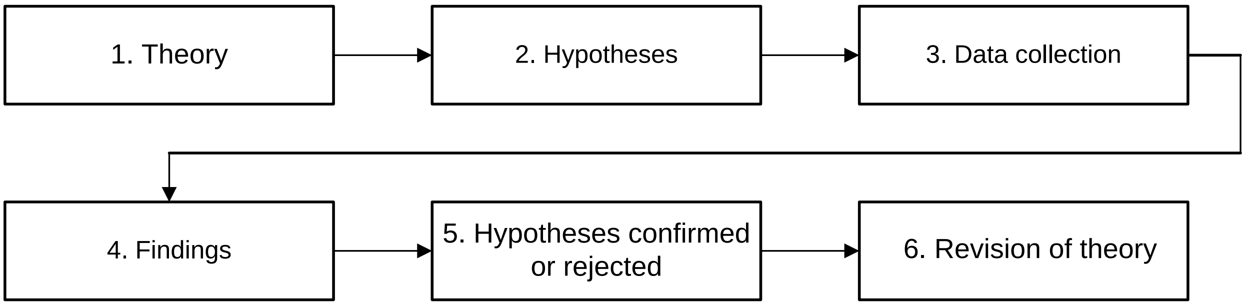


Figure 4.2: The process of deduction

Source: Adapted from Bryman & Bell, 2007: 11.

Bryman and Bell (2007: 11) describe deductive theory as the commonest view of the relationship between theory and empirical research. Accordingly, the researcher deduces a hypothesis from what is known about a specific theoretical domain and then subjects the hypothesis to empirical scrutiny. Theory comes first and drives the formulation of hypothesis and the subsequent process of data collection. Ultimately, the final step in the sequence depicted here involves induction, when the researcher infers from the results in a particular domain of research the wider implications to be fed to his discipline and to the wider scientific community.

Welman and Kruger (2001: 22) provide guidelines of how to formulate the hypothesis. It involves converting the research problem into a statement about a relationship between two or more variables in a specific context. Typically, knowledge of these variables and their relationship follows from the preceding literature research and the theoretical setting constructed as a foundation for the research. Although the research hypothesis is deduced from these theoretical foundations, the counter hypothesis amounting to the opposite of the research hypothesis is, in fact, the one subjected to testing. This practice comes from the convention that the researcher must be the sceptical observer. He wants to test the theory under examination as best as possible, with the most stringent tests and with the statement encapsulated in the null hypothesis that his theory will fail these tests. Should the theory not fail, then the research hypothesis becomes true. The standard convention proposed by Christensen (1997: 121) is consequently followed in this study, i.e. to refer to the research hypothesis as the alternative hypothesis, and to the counter hypothesis as the null hypothesis. The alternative hypothesis represents the relationship among the relevant variables under investigation, whereas the null hypothesis typically represents a statement of no relationship between these variables. From the above follows consequently the formulation of the hypotheses for this study:

H^0: The null hypothesis is that the functionality grid does not enhance MOT practitioners' technological literacy.

H^1: The alternative hypothesis is that the functionality grid enhances MOT practitioners' technological literacy.

The alternative hypothesis arises from the fact that the functionality grid makes for a good fit to the paradigm template. It follows then that it must be able to offer the intellectual foundation, the basis of technological knowledge and the practical toolset to enhance technological literacy. Should it do so, it passes yet another test of compliance with the empirical requirements of a paradigm. The logical next step is to focus on the design of the experiment itself.

4.4.2.3 The pretest posttest design

The research design links the research question to the research methodology to be employed in order to generate answers to the research question (Mouton, 2008: 11). In this instance, the research question to be investigated is whether the functionality grid enhances MOT practitioners' technological literacy. This question of course follows from the hierarchy of outcomes. In other words, if the theory creates a positive and enlightening mindset upon technology, and if it improves technological knowledge as has been reported during the interviews, it must be demonstrated to enhance technological literacy.

In response to the research question, the pretest posttest design represents an experimental methodology which is held as true design which when correctly employed yields evidence from which causal inferences can be made. The classical experimental design, according to Bryman and Bell (2007: 45) requires two groups, i.e. an experimental and a control group respectively, to which respondents are randomly assigned. An intervention, or experimental treatment, is the next requirement. This forms the basis for manipulation of the independent variable, because this variable is postulated to be the cause of the presumed effect on the dependent variable (Christensen, 1997: 193).

Both groups are measured before the intervention on the dependent variable, as well as after the intervention. The difference between these pretest and posttest scores is tested statistically to assess the effect of the independent variable on the dependent variable. Control groups and random assignment help to assure that the post-intervention difference between the two groups can confidently be assigned to the experimental manipulation of the independent variable.

These elements together represent the pretest posttest design, also described by Christensen (1997: 339) as the before-after design, and by Dimitrov and Rumrill (2003: 160) as the "randomized control-group pretest-posttest" design. According to Christensen (1997: 339), this design does a good job of controlling extraneous variables such as history and maturation. In the former, this means any historical event which may have affected the dependent variable between the pretest and the posttest would have impacted both groups in the experiment. Similarly, in the latter this means that any changes in the internal conditions of the respondents in the one group over the passage of time would equally manifest in the other group. Combined, these control measures strengthen the internal validity of the experiment; in other words, the researcher can be more confident of the degree to which the intervention upon the independent variable makes a difference upon the dependent variable in the experimental settings set up for this purpose. This design is notated in Figure 4.3.

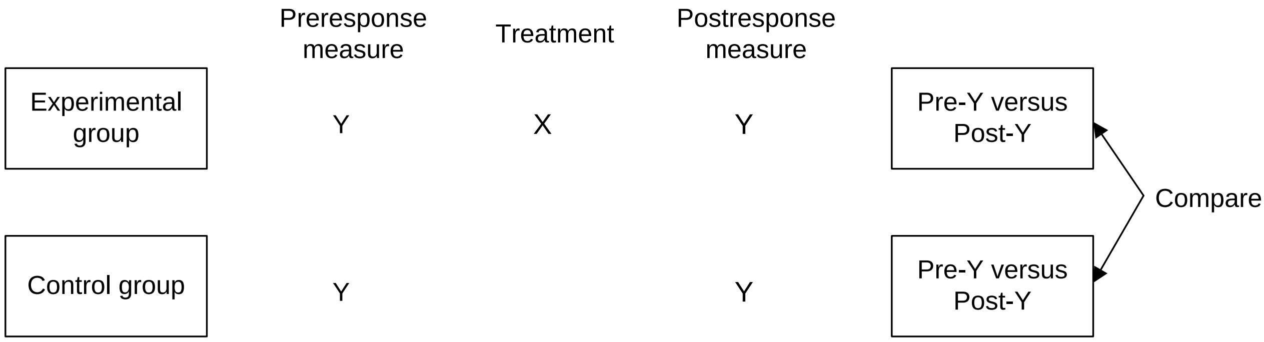


Figure 4.3: The pretest posttest design

Source: Adapted from Christensen, 1997: 339.

Interaction between pretesting and intervention is yet another threat to internal validity, and this needs to be controlled by carefully managing the pretest so that it does not sensitise respondents and prompt them to respond in the posttest differently to the treatment than would they have done with no pretest (Dimitrov & Rumrill, 2003: 160). Dimitrov and Rumrill (2003), Shaffer, Jacokes, Cassily, Greenspan, Tuchman and Stemmer (2004) and Sindre, Natvig and Jahre (2009) present useful examples of how the pretest posttest design works. According to Dimitrov and Rumrill, this design is widely applied in behavioural sciences, primarily to compare groups and or to measure change after experimental treatments. Sindre *et al*. (2009: 12) describe it as the most recommended experimental design when comparing the effectiveness of learning activities.

4.4.2.4 Development of the variables

From the research question it follows that the independent variable is the functionality grid, and the dependent variable is technological literacy. In its most basic iteration, this relationship is denoted as follows:

Functionality grid = independent variable

Technological literacy = dependent variable

Resolving how variation in the independent variable is to be achieved, leads to the question of how the independent variable is to be developed and operationally applied. The functionality grid is abstract and theoretical, and it has to be translated into operational terms. For this experiment, the functionality grid is operationally defined and applied in the format of a formal lecture, appended as Appendix 8. This lecture consists of a number of key concepts and practices which as a combination is meant to show how the functionality grid creates knowledge of what technology is, what it does and what its outcomes are. The intention is to generate technological knowledge and ultimately to enhance technological literacy as per the stated hierarchy of outcomes.

This lecture is a newly created construct compiled specifically to serve as independent variable in the pretest posttest experiment, but its demonstration of practical examples is adapted from methods, and their application in practice, as they have been developed and refined for the purposes of the *Technoscan® Newsbrief*. There are two reasons for using practical examples as demonstrated in the *Technoscan® Newsbrief*. First, promoting the same method which is described as a paradigm attribute in the paradigm template exercise helps to create more momentum and more application for this method and helps to expand its reputation as part of an exemplary solution. Seen from the MOT perspective, it would be irresponsible not to leverage a method which has matured into a standard, and which is shown to be increasingly adopted by MOT practitioners. Second, replicating a tested and proven method helps to ensure construct validity, which is described by Christensen (1997: 207) as the extent to which the conceptual variable of interest, i.e. the functionality grid, can be inferred from the operational definition of this construct, i.e. the formal lecture.

The dependent variable has an important function. It is designed to measure and give a picture of the effect of the variation or manipulation of the independent variable (Christensen, 1997: 213). To achieve this objective, a dependent variable must be selected that will be able to register the variation wielded by the independent variable. The key principle for experiments of this nature is the level of commitment expected from the participant. More commitment equals more confidence in the results, because it reduces the possibility for faking the results and increases confirmation that the construct of interest is really being measured (Christensen, 1997: 216).

For this particular experiment, technological literacy serves as the dependent variable. It manifests in practice as the percentage scores of respectively the pretest and the posttest which form part of the experiment. As a result, the dependent variable in fact consists of a measurement instrument constructed for these tests. A more advanced iteration of the relationship between the independent and dependent variables can now be denoted as follows:

Independent variable = functionality grid = formal lecture

Dependent variable = technological literacy = test score

The pretests and posttests, which appear as Appendix 9 and 10 respectively, consist of short descriptions of technologies representing the latest technological trends described in Chapter 1. These technologies were randomly selected from a list of 25 technologies compiled from a regular column titled *Techtalk*, appearing in the South African edition of the magazine *Popular Mechanics*. The technologies covered in *Techtalk* are without exception all still in an early stage of their lifecycle and none of them have reached the stage where they are in production. Examples were chosen from a date range starting February 2008 and ending February 2010. As in the case of *Techtalk*, every technology in the pretest and the posttest is described in a short manner to make clear their basic essence, operational action and outcome. Four questions follow each description. The formulation of these questions derives from the logic of the functionality grid itself. As an extract from the posttest, the next example serves to demonstrate the practical result:

Technology:
Light-emitting diodes

Description:
Light-emitting diodes (LEDs) are more efficient than incandescent bulbs, but they are not bright enough to use indoors. Scientists have now increased brightness of LEDs by punching tiny, nanoscale holes into their surfaces, allowing more light to shine through.

Test questions to be answered:

Question 1: What is the essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

The pretest consists of five technologies and their sets of questions, and the posttest consists of 10 technologies and their respective sets of questions. The questions are the same for both tests, so as to keep the tests standardised. To limit the carry-over effect and to make sure that participants' experience of the pretest does not influence the validity of the posttest, these tests have different sets of technologies. The answer sets replicate the same pattern and present an answer to each question for every test. These answer sets appear in Appendix 11 and 12. In this regard, the reader is reminded that the outcome pursued is to assess whether the logic and structure of the functionality grid influence participants' conception of how technology essence, action and outcome evolve. This outcome closely synchronises with the content of the lecture about the functionality grid as independent variable, the objective of which is stated above to create knowledge of what technology is, what it does and what its outcomes are. The answers are judged with an open mind, because most of these technologies may validly be described in more than one way. An exactly correct answer in most cases is therefore neither possible, nor required. It makes evaluation more difficult, but given the level of difficulty of the technologies used, and the range of possibilities which their constitution brings to bear within the frame of reference of the functionality grid, multiple choice answers were not deemed appropriate.

Instead of the intervention of the experimental group, the control group receives a placebo in accordance with the pretest posttest experimental design. The placebo is appended as Appendix 13. It represents an interesting discussion about genomic manipulation demonstrated by the Craig J. Venter Institute in the USA. This discussion is chosen for its relevance, its concurrency and for its technical nature. As a placebo it is intended to keep the participants committed to the experiment and to have them believing that they receive a genuine intervention.

The two issues which arise from the above operational definition are the reliability and the validity of these tests as they measure technological literacy as the dependent variable. According to Christensen (1997: 217), reliability can be established by measuring the consistency by which responses are made to the dependent variable in its practical application. This, however, is a principle that can only work with repeated application of the same test over a longer period of time. In fact, Christensen proceeds to describe how most single occasion experiments in Psychology yield unreliable results. But, at the same time, reliability must be seen in the proper context. Nicewander and Price (1978: 408), for example, point out that low reliability in a difference score, in other words the scores of different groups in the same experiment, is not sufficient evidence to conclude that the experiment is faulty or did not succeed, and it should not inhibit the researcher in testing the null hypothesis of no difference. More thought is therefore required on this matter.

For the purposes of this study, establishing reliability lies first in the design and implementation of a pilot exercise as a precursor to the formal experiments, and second in the fact that two experiments involving different methods were to be conducted. The pilot study should yield to the researcher a set of proxy responses demonstrating the experimental variables in action, as well as offering an opportunity to identify weaknesses in the research design.

4.4.3 Development and implementation of a pilot study

4.4.3.1 The rationale for a pilot study

The final step required to complete the preparation for the quantitative experiment was a pilot study. This exercise was to serve as a basic prototype of the tools to be used in the real experiment, as well as to stress test assumptions and conceptual outcomes.

According to Christensen (1997: 424), a pilot study is a rehearsal of the experiment with a small number of participants. Very relevant for this study, especially given the fact that it uses constructs which have not been deployed or tested before, he also describes the pilot study as a pretest which should be conducted in the same scientific spirit as the final experiment. In the same vein, Bickman and Rog (2009: 227) describe yet another role of a properly conducted pilot study, i.e. that for qualitative research it helps to generate understanding of how the elements involved in a study allocate meaning to the constructs operationalised in the study. Conducting a pilot study would therefore benefit both experiments for this study.

With specific reference to experiments, Christensen (1997: 424), lists several additional and very relevant benefits of the pilot study: 1) It helps to assess whether the independent variable produces the intended effect and it presents an opportunity to first assess what went wrong should the intended effect not have been elicited, and second to refine the intervention until the right effect is elicited; 2) similarly, the sensitivity of the dependent variable can be assessed; the pilot study may also show the dependent variable too unrefined to register the effect of experimental manipulation; and finally 3) it presents the opportunity to experience the full experimental procedure and its sequence.

4.4.3.2 Preparation and launching of the pilot study

This researcher is employed by the City of Cape Town (CoCT) in South Africa as the financial manager for the Information Systems and Technology Department. CoCT is the capital of the Western Cape Province, and with 3 million citizens its average budget in 2010 exchange rate terms was in the vicinity of US$ 3 billion. It has 25000 employees, of which 14000 are computer users and of which approximately 1000 can be seen as knowledge workers. These knowledge workers are typically managers or analysts with tertiary qualifications. They are all equipped with modern laptops and have access to the Internet and the city's intranet via a wireless network. Of course, it also means they are busy professionals with little spare time. Like most of its peers, CoCT as yet does not a have a position for a CTO, nor does it have a formal innovation management policy. But typical of local government it consists of multiple business units active in a large number of disciplines. Accordingly, it maintains a sizeable investment in a wide range of technologies, including a wind farm.

Given the apparent benefit to research effort and costs, combined with the CoCT's profile as a megacity, a request was directed to the Chief Information Officer (CIO) to use the city's ICT network, and specifically the Intranet, to conduct the pilot study. The CIO agreed to the request, with one important proviso, viz. the researcher would not be allowed to send out a bulk email message to request participation. To overcome this constraint, 10 potential participants known to the author were approached individually with a request to participate. In order to match the profile of the participants in the final experiment, two conditions applied for participation in the pilot exercise, viz. each needed to have at least a first university degree combined with five years of working experience. Each of the first 10 participants was also requested to name more candidates who they thought may match the requisite profile and who may be willing to participate.

Pending finalisation of names for participants, colleagues in the Department of Information Systems and Technology helped to upload and organise the research material, as well as to save it on an Intranet site created for this purpose. The first formal draft of a lecture about the functionality grid was ready to be launched, combined with a test as well as a review questionnaire. The mode of delivery of the lecture at this stage became an important matter for consideration. For the purposes of the main experiment, therefore, the set of considerations which was to apply needed to be considered carefully, as the pilot needed to demonstrate the same mode as was to be used in the main experiment. For example, at first consideration was now given to deliver the lecture in a formal class setting. Understandably though, class time of MBAs comes at an unaffordable premium, apart from the fact that scheduling for full-time, part-time and modular students held the potential to become a logistical gridlock. The second mode considered for the lecture was a podcast consisting of a video of the lecture presented by the author in a formal class setting. The obstacle here was the size of the electronic file, which would make downloading of the electronic content almost impossible, especially in South Africa and the rest of the developing world, where bandwidth remains a scarce and expensive commodity. Finally then, and in consultation with a professional digital content producer, a slide cast (in other words, a simple slide presentation combined with voice and text) was chosen as the most practical option. It was also by far the cheapest in terms of production and bandwidth costs. Apart from these benefits, the slide cast could be produced by the author, and repeated recordings and refinements to the text were possible until the author and his promoter were satisfied that a proper standard towards presentation had been achieved, first for the purposes of the pilot study and then for the final experiment.

The number of volunteers for the pilot study, not unexpectedly, increased very slowly. Even though 25 of the 30 names wanted for the pilot study had initially volunteered, the author needed to add additional names for the inevitable attrition that could be expected from the date of volunteering to the date of finally launching the pilot study. Several colleagues were simply too busy. They are executives and tend to work during the evenings and weekends as well. Appendix 15 represents a typical example of a colleague wanting to participate, but simply being too busy. Her highest qualification is an MBA degree from the USB and she had the intention to do a PhD at the USB as well. A perfect candidate, yet eventually she could simply not find the time to participate. Her example held however valuable lessons insofar participation in the final experiment was concerned. A second request therefore went out, asking potential participants to consider participating in the pilot. This request, however, was directed at a new group of names provided by the volunteers who had already indicated their willingness to participate. Ultimately, five additional volunteers made for the practical threshold of 30.

The final content for the pilot study consisted of the slide cast lecture about the functionality grid, the post-intervention test and a short review questionnaire. The lecture is already referred to as Appendix 8 [taking into consideration that Appendix 8 represents the final version refined after the pilot], while the pilot test and the short review questionnaire are appended as respectively Appendix 16 and 17. The slide cast lecture had a run time of 23 minutes. New material produced for the pilot study consisted of the test itself and the review questionnaire. The test consisted of five technologies randomly taken from the original list of 25 technologies compiled for this study. The test questions reflected the initial structure conceived for a test of this nature. Although the two group pretest posttest design of the final experiment had already been resolved at this stage, expecting busy professionals who had volunteered for the pilot study to complete the full sequence of the final experiment was not considered a viable option, given the replies forthcoming from colleagues requested to participate and the time it was estimated to be required for completion of the full sequence. So, the final design for the pilot study consisted of the one-group after-only design, comprising only one group receiving an intervention and a posttest. This meant no pretest and no control group, which as reported earlier are seen as weaknesses of this design. Apart from these weaknesses, all other control measures were however pursued as best as possible, even though this was only a pilot exercise.

The sequence which ultimately applied was in accordance with the set of instructions and meant that the participant was to study the lecture, complete the test and offer a review of the exercise. The review questionnaire was compiled in order to refine the experimental material and the planning for the final experiment, and it only required a tick in a box across each option for each question. But it included two questions formulated to gauge the effect of the functionality grid on the participants to the pilot exercise. These questions were as follows:

1. Do you think you have now a better understanding of the basic tenets of technology?
2. Please give your overall impression of this exercise?

The final instructions for completion of the pilot study, included as Appendix 18, went out to the volunteers on 15 May 2010. As can be seen from these instructions, participants had several options for receiving the intervention. The first and simplest option was to follow the default setting, i.e. an automatic slide show combined with voice. It could however not be assumed that all the participants had access to good sound equipment, if at all, so the next two options were to either follow the slide show with the text notes on the screen, or to follow the slide show and the text notes printed out. The recommended option to maximise internalisation of the lecture content was for participants to follow the slide show with voice and to use printed out text notes for final capturing of the content. Furthermore, to ensure participants kept momentum once started, the requirement was for the lecture to be studied and the subsequent test to be completed within 24 hours. This control measure was inserted primarily with the real experiment in mind, so as to minimise the chances for other events to occur between the pretest and the posttest and thereby influencing the participant's submission for the posttest. But a secondary role for this measure was also to help ensure momentum and completion of the sequence. This measure was not to test memory, because the experiment, after all, was to assess participants' understanding and insight. The stated deadline served the same objective, i.e. to encourage completion of the required sequence and delivery of submissions. It is worth noting that the deadline in the end served only this purpose and was not mentioned again in follow-up email reminders. On 9 June 2010 the 30th and final submission was however received back. This data was now ready for analysis and for a synthesis of the lessons to be learned towards conducting the final quantitative experiment.

4.4.3.3 Results of the pilot study and lessons learnt

The results of the pilot study and the review questions are presented in respectively Tables 4.1 and 4.2.

Table 4.1: The results of the pilot study

Description	Outcome
Highest score	90%
Lowest score	15%
Average score	58%

Source: Author's own, 2010.

Table 4.2: The results of the review questions

Description	Outcome
Average time to study intervention	Between 60 and 90 minutes
Average time to complete test	Between 60 and 90 minutes
Average impact of intervention	26 out of 30 participants felt they had a better understanding of technology after the exercise
Average impression post-intervention	26 out of 30 participants had a positive impression of the exercise

Source: Author's own, 2010.

From the review questions, it becomes clear that the participants' first option for receiving the intervention was the slide show combined with voice on the screen. Twelve of 30 participants followed this option, while 10 preferred the slide show with voice and text notes combined. The rest did not use the voice facility and settled for the slide presentation combined with text notes.

The average time period to complete the intervention in the format of the lecture was between 60 and 90 minutes, and the average time period to complete the test itself was between 60 and 90 minutes. The average score for the test is 58 percent, which is indicative of the degree of difficulty of the test. A frequency distribution of the test scores is depicted in Figure 4.4.

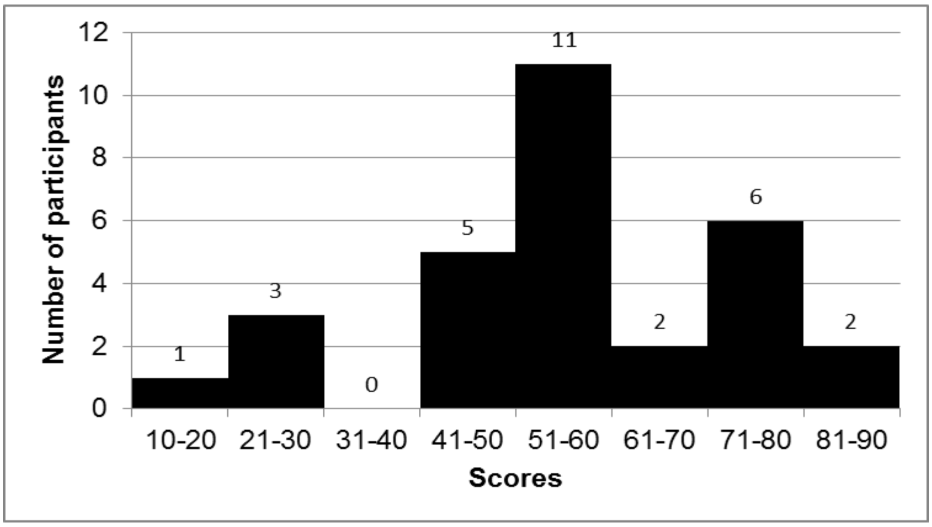


Figure 4.4: Frequency distribution of the results of the pilot exercise

Source: Author's own, 2010.

Most of the participants felt they had a new and refreshed perspective of the basic tenets of technology, and most had a positive impression of the exercise.

Apart from several telephone and personal discussions, some of the participants replied via email with their comments. These comments appear below:

Comment 1: "I would have preferred more rules in a decision tree format to assist in the nine-cell assignment such as used in time management assessment of tasks for prioritising" (sic).

Comment 2: "Here is my effort. I have enjoyed it". (Translated from the original Afrikaans version.)

Comment 3: "Herewith my input regarding your study. I must apologise (sic) for only submitting my part so LATE. I tried my best to complete it as per your instructions. I must confess, this was not an easy exercise, however, it was challenging and a great learning curve".

Comment 4: "The matrix did nothing to structure my thoughts or to make me think different about technology". (Translated from the original Afrikaans version.)

Generally, participants showed a healthy interest in the research, and the majority found the specific approach encapsulated by the functionality grid as very stimulating. The new perspectives they gained of technology trends, technology diversity and its modern manifestations were much appreciated by the large majority of the participants, and such became clear in the personal discussions as well. Where participants were not satisfied, they felt that the particular kind of framework simply did not work for them. The first comment above is from a participant with an MBA from the USB. He wanted a decision tree. The second comment is from a participant with a master's degree in Geography, the third from a participant with a master's degree in Public Administration. The fourth and final comment is from a participant with an honors degree in Economics.

From the pilot study it is possible to draw the following conclusions regarding, first, the evaluation of the functionality grid, and second, regarding the methodology envisaged for the main test.

First, although the pilot study did not have the rigour of the main quantitative experiment, there were indications in the comments of participants that the functionality grid causes a noticeable impact on the mindset of the majority of participants. Second, the majority of participants also reported an improvement in technological knowledge. Third, there is preliminary evidence of improved technological literacy, in that the sample of participants was able to earn high scores in a technology classification experiment. These findings proved that the tests designed for the main experiment were ready for implementation insofar it concerned relevance to the hierarchy of outcomes.

As far as conclusions on methodology are concerned, the pilot study firstly proved the construct validity of both the independent and the dependent variables, represented respectively by the lecture about the functionality grid and the test for technological literacy which followed upon the lecture. Secondly, it proved that the formal lecture had reached an acceptable point of refinement, with minor exceptions. Thirdly, it showed that the test questions were basically ready to be applied in the final experiment. Fourthly, it demonstrated that the combination of an intervention followed by a test had reached an acceptable point of refinement, once again, with minor exceptions. Fifthly, and finally, the pilot study also provided lessons about several difficulties ahead, specifically that it was going to be difficult to generate interest in the study among the potential participants for the main experiment, and that the exercise is intrinsically difficult even for well qualified knowledge workers who enjoy a good measure of career success in a difficult and challenging operational environment.

4.4.4 Data collection

4.4.4.1 General overview

The pilot study gave a green light for the main experiment to go ahead. The following section therefore describes the considerations and preparations related to data collection for the main experiment.

According to Brewer and Hunter (2006: 47), a triangular data model ensures a multifaceted empirical view upon the theory under investigation and helps to lay out the complex strands of its practical implications. Each method presents its own strengths and weaknesses. The pretest posttest design, in its turn, offers the best methodology for producing evidence which makes the examination of causal ties between variables possible. But for this study the pretest posttest design also required the most preparation and most of the resources allocated to execution of the overall research strategy. This proves again the point made by Brewer and Hunter (2006: 76) that methods such as experiments require more resources in the design and instrumentation phase.

The following discussion presents an overview of the processes followed to implement and complete the quantitative experiment to the point where it generated the data required to answer the research question. The first topic to be discussed is validity. This is followed by a discussion about the mode of delivery of the experiment, while the final section describes the practical implementation of the experiment and its results.

4.4.4.2 Internal versus external validity

Much thought and deliberations went into the final preparation of this experiment. Following upon the pilot study, the elements put on the table were respectively a readymade lecture representing the functionality grid as the independent variable, and the combination of a pretest and a posttest representing technological literacy as the dependent variable. From here onwards, the most important matter which needed clarification was to consider who the participants were to be.

The typical research project requires the selection of a sample of participants from a particular population of interest to the researcher. Beyond clarification of the research variables, this requirement obliges the researcher to clearly identify his units of analysis about which data is to be collected (Brewer & Hunter, 2006: 79). Finalising the units of analysis is a matter of resolving what types of objects are theoretically relevant to the study, and together with sampling they form part of the larger set of considerations involving the research aims, the research objectives, and the feasibility of the plan formulated to achieve these outcomes.

The priority for these experiments as second phase of the research strategy remains to reinforce the theoretical foundations set in the first phase. This manifests in a very deep focus upon the functionality grid as a contesting theory, and means that internal validity is a priority for this study, at least insofar it concerns technical requirements for research of this nature. The intent was never to generalise beyond the confines of this study. Seeking participants, the logical next step was to consider a student sample, and specifically a convenience sample.

Using students as respondents is a topic well covered in the research literature. For this study, and specifically given its intended contribution to Economic and Management Sciences, a timely contribution in this regard is Bello, Leung, Radebaugh, Tung and Van Witteloostuijn (2009), writing as editors of the *Journal of International Business Studies*. In their contribution, Bello and his co-editors explain the merits of using student samples and the policy their journal maintains in this regard. According to them, using a student sample is generally not seen as a sensible research strategy, even if it is a popular cost containment strategy. Specifically, students are not typically employees or managers with relevant work experience. When students form part of a sample with specific age and life-stage characteristics, it could lead to bias in the findings and this, again, must be recognised as potentially contributing to a lack of external validity and generalisation of the obtained results. Distinction must, however, be made between research about “fundamental” processes which can be seen as independent of context and life experiences, and “proximate” processes (Bello *et al*., 2009: 362), where the focus is more on a specific context and less on the basic human nature, for social science at least. In the case of the former, internal validity is key, whereas in the latter external validity enjoys priority. While findings about fundamental issues can be generalised, outcomes sensitive to contextual settings are unlikely to lend themselves to generalisation across different segments of the population. This distinction is therefore the same as the distinction between basic and applied research to be drawn below. Using MBA students with the appropriate academic profile is however held as an exception to the general rule. Apart from cost, *bona fide* practical considerations such as the nature of the research topic, the nature of the experiment and the profile of the MBA cohort, may then justify the use of an MBA student sample. It is, again, a matter of research question-design fit, but the burden remains on the researcher to demonstrate with an explicit discussion why external validity need not to be a priority when compromised.

As a typical example of basic instead of applied research, the focus here is indeed much more on internal validity. This trend is recognised by Bickman and Rog (2009: xiii) who write that internal validity is an important consideration to both kinds of research, but that external validity is much more important to applied research. The focus on internal validity is also typical of formal experiments. Bernard (2000: 108), for example, writes that controlled experiments have the “virtue” of high internal validity and the “liability” of low external validity. To Welman and Kruger (2001: 119) experimental research for management insight determines that internal validity be dealt with as a first priority, because the purpose is to seek for relationships between management phenomena first and foremost. Insofar it concerns external validity then, knowledge of any population is valid as long as it is presented as only knowledge of that population. Against this, Bryman and Bell (2007: 169) state that quantitative researchers in general set a high priority upon generalisation, as they do for virtues such as measurability, causality and replication. But they also describe generalisation, hence external validity, as a “preoccupation…focused on law-like principles about human behavior”. This study is adequately proven to be about fundamental issues, and to be primarily a contribution at a theoretical level.

With internal validity as a key consideration, it should be pointed out that students typically may again pose a problem. Due to a lack of experience, they may not have the requisite knowledge to adequately respond to the experimental treatment or survey questions, which serves as threat to internal validity. MBA students are seen as an exception to the above rule, because they typically have had work experience or continue to study part-time only. Yet another defence against this threat is to use a specific experimental research design such as the pretest posttest where the base level of knowledge is set with the pretest. At the same time, the true nature of this design bolsters internal validity further by the presence of the control group against the experimental group and random assignment of participants to these groups.

With the above basis in place, permission was requested from USB to use the full cohort of its MBA students as target population. As post-graduate students who typically have had work experience and often would have found themselves in the role of MOT practitioner, they presented an adequate academic profile for the purposes of this experiment. The request to the USB went out on 12 January 2010 and is attached as Appendix 19. Given the nature and context of the research, this business school granted the request on condition that using its MBA students was recognised as a convenience sample which would limit generalisation of the study.

Following the successful completion of the pilot study, this step finalised the most important set of considerations towards putting in place the quantitative experiment. All the elements were now ready for implementation, and the focus needed to shift to operationalisation.

4.4.4.3 Mode of delivery

Using the MBA cohort at the USB was eventually to have another important economy of scale benefit to this study. This school uses an Internet-based learning tool known as Web Course Tools (WebCT), specifically designed for electronic delivery of academic courses. Originally from the University of British-Columbia, WebCT is a well-known software product which presents the significant advantage of also supporting the delivery and use of multimedia elements, such as sound, video, and interactive hypermedia. As a delivery tool for the content of this experiment, its merits were already in place. Burgess (2003: 14), for example, found that the majority of graduate students in her study to determine WebCT's feasibility as a tool for delivery of learning content adjusted to the tool quickly and with enthusiasm. As was the case with the pilot study, the benefits of conducting this experiment through the Internet were obvious. Upon request, permission was therefore granted to the researcher to use this tool, and much assistance was subsequently to be had from the relevant supporting staff at the USB.

Using WebCT to conduct the experiment held two additional and very significant implications. First, it meant that the full MBA cohort of 650 students, consisting of full-time, part-time and modular students across their first, second and final years, and irrespective of where they found themselves, could be targeted with the request towards participation. This also meant that valuable study and class time at the school itself did not have to be sacrificed in conducting the experiment, which in turn meant that very busy students who were already under pressure to perform were allowed the opportunity to more favourably consider participation in the experiment. Secondly, it meant that the specific programme and time span for conducting the experiment could be managed in a more flexible manner, which in turn held the benefit of generating more interest and possible participation.

4.4.4.4 Sampling, participants and content

The pilot study showed that the main experiment could go ahead. Two important building blocks first needed to be put in place however. They were to recruit willing participants in a scientifically responsible manner, given the already stated constraints and considerations, and to fine tune the content for the experiment.

Given that the USB agreed to the request for using its MBA students, a key principle to consider was whether a sample could be drawn from the full MBA cohort. This approach, however, assumes that, if sampled, the individual student would be willing to become a participant. This was not the case. The permission from the USB did not mean that MBA students were obliged to participate. So, to use the class list as a sample frame for the population of interest, and to draw a sample of students from here, was not possible. The only alternative was, again, to request voluntary participation. The convenience sample could however be conducted in a fair manner, making it equally probable for each member in the cohort to become a participant. Other than membership of the USB MBA cohort, no condition was put forward towards participation. Volunteers could be full-time, part-time or modular; they could be located anywhere in the world, and although a time limit was more than once stated in order to encourage completion, no one volunteer was excluded from the process based on time or late submission.

The request to participate, appended as Appendix 20, went out to the full cohort via email on 23 June 2010. At the same time, permission was granted for a short appearance in front of the full-time students for a short motivation of the study and to request participation. These full-time students were however only a small minority of the full cohort. In response, 57 MBAs volunteered to participate by 1 July 2010. On this date, a reminder went out to all MBAs excluding the 57 who had responded. This reminder is appended as Appendix 21. On 14 July 2010, altogether 95 MBAs agreed to participate in the experiment. Given the nature of the experiment, the slow pace of responses and keeping in mind that the volunteers could not be kept in limbo for much longer, it was decided to open the exercise. Further justification to this decision was the fact that late volunteers could easily be accommodated, given the nature of the exercise.

Before opening the Lochner PhD research module on WebCT, as the exercise came to be known, final refinements were due in the content. The pretest and the posttest had one critically important change, brought in after consultation with the Centre for Statistical Consultation at the University of Stellenbosch. Whereas the pretest showed a diagram of the functionality grid in order to make it easier for the uninitiated participant to give an answer to Question 4 of every device to be responded to, the posttest did not have this benefit. The difference can be seen below, where the pretest is accompanied by a diagram of the functionality grid, and the posttest is not.

Pretest:

Question 4: Altogether, in which cell of the functionality grid does this technology belong?

Functional outcome:

		Positioning this technology in the functionality grid		
		Action		
		Process	Transport	Store
Output	Matter (M)	Cell 1: Transforming substances	Cell 2: Moving substances	Cell 3: Holding substances
	Energy (E)	Cell 4: Generating energy	Cell 5: Transmitting energy	Cell 6: Keeping energy
	Information (I)	Cell 7: Composing information	Cell 8: Sending information	Cell 9: Saving information

Posttest:

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

Even if the intent was to help those uninitiated participants in the pretest, the line of thought which developed from here was that a carry-over effect may develop from the pretest to the posttest. In other words, introducing the functionality grid in the pretest would allow the control group to gain insight into the nature of the theory and how to apply it in order to answer the posttest. This could possibly destroy the potential of the intervention to show its real effect. Besides this danger, the pretest and the posttest needed to maintain the same format and the same formulation for the questions, with only the technologies used as case studies in these tests to change from the pretest to the posttest. The decision was therefore taken to remove the diagram of the functionality grid from the pretest as well, and to insert precisely the same formulation of Question 4 into the pretest as was the case with the posttest, i.e. "Think of an appropriate technology classification scheme, and then state…" as it appears above.

The formal lecture was also recorded again several times to create the best voice quality possible. The content of the presentation itself was refined for greater clarity, with better examples demonstrating the principles of the functionality grid and for completeness of the message, given that it was to serve as the independent variable.

A final requirement was for the pretest and the posttest to each have a set of instructions which could guide the participant through the process. These instructions needed to be as clear and as succinct as possible in order to avoid any confusion, mishaps or frustration with the completion of the exercise. In consultation with the WebCT instructor at USB, these instructions were subsequently formulated, assessed for accuracy and finalised as part of the content of the pretest and the posttest which were eventually transferred electronically to the relevant module created for the exercise. These instructions can be seen appended respectively as Appendix 22 for the experimental group and Appendix 23 for the control group.

4.4.4.5 Final implementation and outcomes

The student number for every volunteer was now fed into WebCT, where each number was randomly allocated to either Group A (the experimental group), or Group B (the control group). Thanks to the control measures in WebCT, each participant only had access to his or her own group and the material associated with that group. With these changes in place, a notice informing the volunteers that the exercise had opened went out on 14 July 2010. This notice is appended as Appendix 24. Each participant could now complete the exercise in his own time and at his own pace, and wherever he found himself.

The notice stated a deadline for submission in order to encourage early compliance. By 28 July 2010, only 25 participants had started with the pretest, most of whom had also completed the posttest. On the same day, a reminder went out to those volunteers who had not complied. By 13 August 2010, 42 participants from both groups had completed the pretest, while 32 participants from both groups had completed the posttest. These numbers continued to rise very slowly. By 24 August 2010, 29 participants in Group A had completed the pretest, and 22 the posttest. For Group B, the numbers were respectively 27 and 24. To have these numbers reaching at least the nearest logical threshold of 25 per group for full completion of the whole cycle, volunteers were approached individually. Three examples of this approach are appended as Appendix 25. With data processing and analysis still ahead, time was running out. Consequently, the last statistics were drawn on 6 September 2010 in order to assess progress, weighted up against the benefit of keeping on with reminders from which the yield was by now negligible. The numbers on this final assessment were for Group A 33 completed pretest submissions, and 26 posttest submissions. For Group B they were respectively 28 and 24. The data collection effort was for all practical purposes discontinued after this date. Analysis of the final set of submissions indicated that only

26 participants from Group A had completed the full sequence from pretest to posttest, while only 19 participants from Group B had completed the full sequence.

Three trends were immediately and clearly observable from these final figures. First, only 45 of the 95 original volunteers kept to their undertaking to participate and complete the exercise. From personal messages received in this regard, this trend at least to some extent can be ascribed to work and study loads these volunteers experienced at the time. Related to this, it became clear that completing the whole sequence typically took longer than 90 minutes. Furthermore, the news may have gone around that the exercise was difficult. Such feedback was in fact received from a participant who is known for an excellent performance in class as a fulltime MBA. Allocated to Group B, which constituted the control group, her feedback also explains the second trend which could be observed. This trend is the logically expected lower number of completed submissions found in Group B. They had a placebo as an "intervention", and received no guidance on how to complete a challenging posttest. The final trend was the natural attrition in willing participants from the pretest to the posttest. Not unexpectedly, this trend is ascribed to the typical resistance built up in a situation where the candidate is subjected to a challenging evaluation without any guidance or help. This resistance could be expected to increase where the candidate voluntarily participates in an exercise of this nature.

Email feedback from participants indeed allows much insight into how the process transpired. Some of these comments, generally from those participants positively inclined towards the exercise, appear below:

Comment 1: "I finished it Thanks it was interesting".

Comment 2: "I signed up to take part in your experiment, but only managed to complete the pretest. Don't know if there was a problem with WebCT. I have managed to download the Functionality Grid presentation, but could not complete the post-test!?!? Could not get access to the test. Just loaded and loaded, but nothing appeared on the screen. I Know the deadline was yesterday, could you not perhaps re-open me so I can complete the post-test?"

Comment 3: "Completed. Wishing you all the best with your research".

Comment 4: "Hi Ferdie, I am terribly sorry having missed your initial deadline. I was travelling and have only just returned so will complete it by tomorrow!"

Comment 5: "Consider it done on my side. Jooooooooo, serious technology challenge mos. Remind me of science Olympiad and those complicated engineering tests/exams. Nice mind refreshing. I will need to go back and polish my technology/technical skills. This fuzzy business concepts are contaminating our technology know how gem".

Comment 6: "Apologies for not being able to complete the exercise before the due date due to various challenges. I am back in the office and could assist if still required".

Comment 7: "Well I opened the site and it said Group A (not sure what this means, I assume you do). When I started it a few days ago, I could not turn on my speakers so thought best to sort this out before I continue with the survey. The Instructions said it would be useful to watch the slide show and to lesson, which I eventually did today. It was very helpful, however the questions were quite complex. Not to disappoint you or corrupt your survey with unintelligent answers I did my level best to answer as per your guideline for the 'post test'. Wishing you well and if I can do anything else, please let me know".

Comment 8: "Eventually fulfilled my promise. I found the exercise really interesting and learnt a lot from it – certainly a new way to look at technology and to analyze it". (This comment is translated from the original Afrikaans version).

Some participants were negatively inclined, and they used the space provided for answers in WebCT to make comments. Three examples are shown below:

Comment 1: A general response upon Question 4 in the pretest: "I do not know what you mean by a classification scheme". This specific participant was from the experimental group and achieved 22 percent in the pretest in comparison to 70 percent in the posttest.

Comment 2: A response upon Question 4 in the posttest: "This question is frustrating because I do not understand it". This specific participant was in the control group and achieved 13 percent in the pretest in comparison to 11 percent in the posttest.

Comment 3: "OK, I am sorry, but I do not have time for all these questions. I do not think the lecture really helped my understanding". This specific participant was in the experimental group and achieved 35 percent in the pretest in comparison to 30 percent in the posttest.

The next step in the process was to evaluate the two sets of answers according to the answer sets preset for this purpose. WebCT allows electronic evaluation, even for open-ended questions as was the case with this experiment. An excerpt from WebCT representing the evaluation process is shown in Appendix 25. The evaluation process was kept as simple as possible. A paper copy of the answers for each set of tests served as the guide for electronic evaluation. To maintain consistency, the questions for each test were evaluated across all submissions. In other words, Question 1 of the pretest for all 47 complete submissions was evaluated, before evaluating Question 2. In this process, WebCT again was very helpful, offering the functionality to evaluate per question across both sets of tests, instead of per submission. Again, this option is depicted in an excerpt from WebCT shown in Appendix 25.

In this manner, all submissions were systematically evaluated from the first submission of the pretest to the last submission of the posttest. WebCT also offers a review mechanism which was used extensively to ensure all answers for each specific question were evaluated as consistently as possible. With the full evaluation completed, the relevant scores for each participant were sent to the Centre for Statistical Consultation at the University Stellenbosch. The full set of results is appended as Appendix 26. An excerpt appears in Table 4.3.

Table 4.3: An excerpt of the results for the pretest and posttest

Group	Respondent	Percentage score	Time
Control	1	20	pretest
Control	1	11.25	posttest
Control	2	13.75	pretest
Control	2	11.25	posttest
Control	3	23.75	pretest
Control	3	11.88	posttest

Source: Author's own, 2010.

With the description of the quantitative experiment completed, a review of control measures taken to assure internal validity of this experiment follows as concluding contribution. Christensen (1997: 257) presents a summary of extraneous variables which may serve as rival hypotheses explaining the effect produced in the dependent variable. Taken from Christensen, those extraneous variables most relevant to this study appear in Table 4.4, accompanied by the steps taken to ensure control of these variables.

Table 4.4: Control measures towards internal validity

Rival hypothesis	Control measure
History: potential of event other than the independent variable to occur between the pretest and the posttest.	Instruction to complete full sequence within 24 hours.
Maturation: changes in the conditions internal to the participant, such as hunger, stress, pressure, etc.	Instruction to complete full sequence within 24 hours.
Instrumentation: Changes that occur over time in the measurement of the dependent variable. Human observers are typically subject to boredom, while skills may improve over time.	Electronic process with no human intervention. Pretest and posttest standardised.
Selection bias: Any changes due to differential selection procedures used to allocate participants to groups.	Random allocation to respectively the experimental and the control group by WebCT.
Mortality: Any changes due to the loss of participants from one or both groups.	Common problem for experiments with human participants (Christensen, IBID.: 240). Control measures implemented were generation of interest, making participation easy and convenient, and using an appropriate statistical test providing for groups of unequal sizes.
Participant effect: No participant is ideal, and most over time built up a generally negative perception of the experiment and the demands it posed.	Using WebCT as the familiar tool for content delivery was the primary control measure to counteract this variable. Clear and unambiguous instructions served as secondary measure. Stimulating material also served as a secondary measure. Participants also had the freedom to opt out and some did.
Experimenter effect: The experimenter is the primary beneficiary of favourable results. The experimenter may therefore be biased towards certain participants and/or results.	Methodological measures taken to counteract this variable include avoidance of any personal interaction with participants, other than email messages serving as reminders or as confirmation that entry to the experiment is in place; full electronic sequence of the experiment, where material is fixed for duration of the experiment; pilot study for testing and validating material.

Source: Author’s own, 2010.

4.4.5 Description and analysis of the quantitative data

4.4.5.1 General description

The contribution intended with this quantitative experiment was to demonstrate the impact of the functionality grid across all three levels of the hierarchy of outcomes. With a change in mindset of participants, and with improved technological knowledge, the main aim, however, was to answer the research question of whether the functionality grid as the independent variable enhances technological literacy as the dependent variable. To this end, a formal pretest posttest experiment was conducted with an experimental group and a control group. The results constituted a table of percentage scores for respectively a pretest and a posttest of participants belonging to either an experimental group or a control group. The following section first presents a general description of the data which were generated by the experiment, and then describes a test conducted to assess the assumptions postulated in the research hypothesis.

Only 45 participants out of the original 95 volunteers for the experiment completed the whole sequence consisting of the pretest, intervention, or placebo, and the posttest. The youngest participant was 24 years old, and the oldest 50 years. The average age of the participants was 38 years. The frequency of participant age is shown in Figure 4.5.

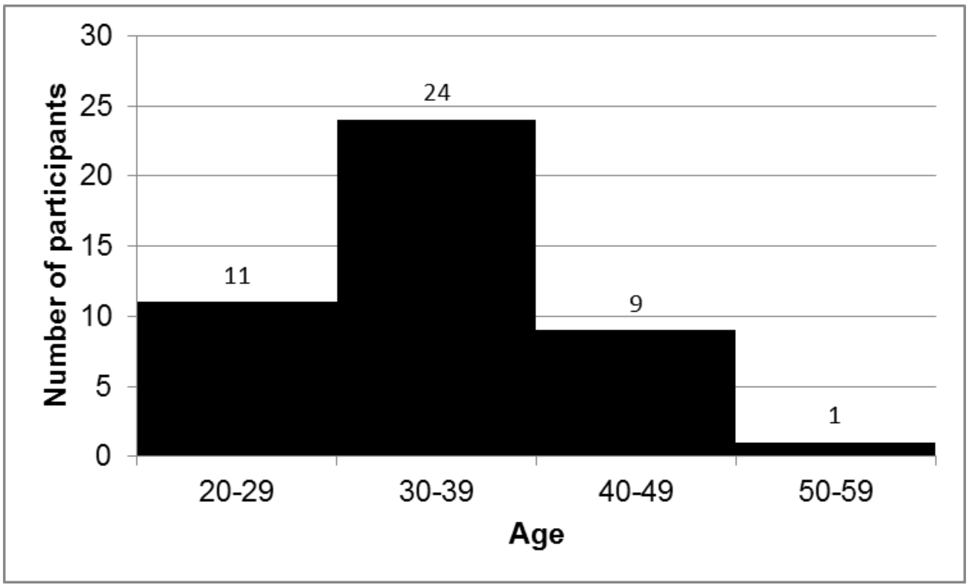


Figure 4.5: Frequency distribution of participant age

Source: Author's own, 2010.

Of the 45 participants, 28 had a second degree. Their careers are classified in Table 4.5.

Table 4.5: Spread of professions among participants

Profession	Number
Managers	17
Engineers	8
Specialists	14
Executives/partners	5
Students	1

Source: Author's own, 2010.

The category for managers contains all the professions where "manager" forms part of the title, and so too for engineers. The category for specialists contains a diverse number of professions where specialisation other than engineering is required, e.g. Senior Business Improvement Specialist, Broker Consultant, Remuneration Specialist, Project Analyst – Business Planning, and Global Strategy Planning and Business Operational Management. With one exception, all the participants were from South Africa, and again with one exception, were full-time employees and part-time MBA students.

The pretest scores for the control group in the order of lowest, highest and average are 13 percent, 46 percent and 24 percent. The posttest scores in the same order are 11 percent, 41 percent and 21 percent. The frequency distribution of these two sets of scores is shown in Figure 4.6. The pretest scores for the experimental group in the order of lowest, highest and average are 11 percent, 44 percent and 23 percent. The posttest scores in the same order are 31 percent, 70 percent and 51 percent.

When the scores for the experimental and the control groups are combined for respectively the pretest and the posttest, the marked shift to the right, and higher scores, can be seen from pretest to posttest. These frequency distributions are depicted in Figures 4.6 and 4.7.

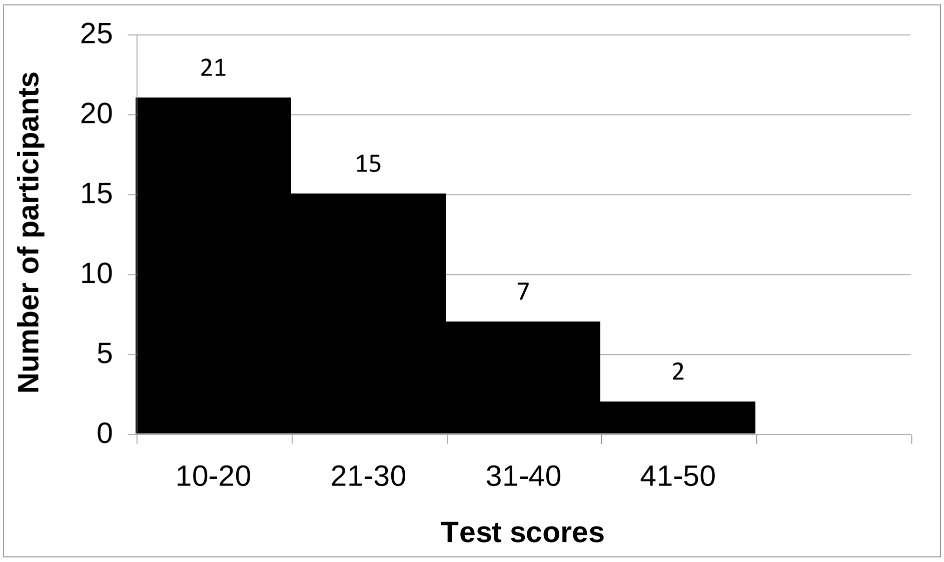


Figure 4.6: Frequency distribution of pretest scores

Source: Author's own, 2010.

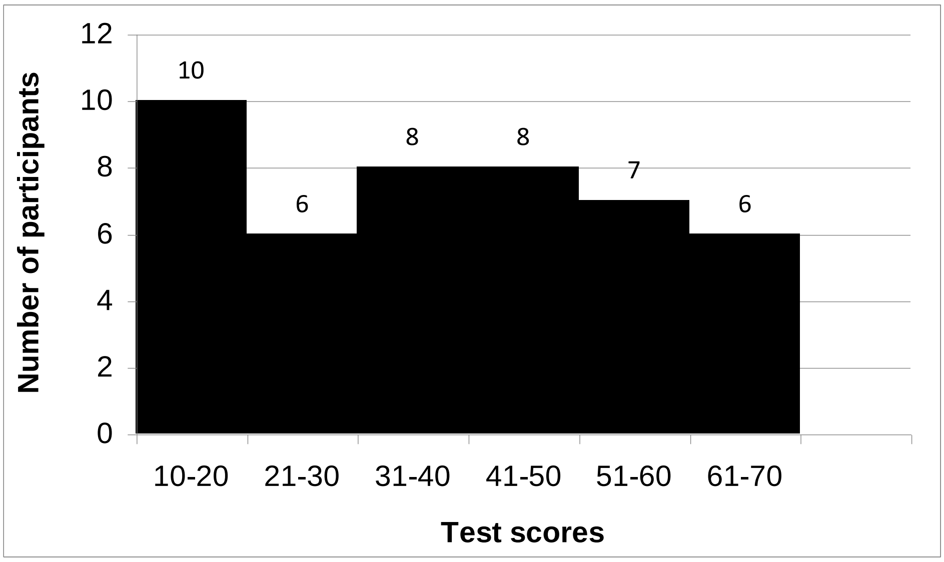


Figure 4.7: Frequency distribution of posttest scores

Source: Author's own, 2010.

The distribution of values and the amount of variation in the data set are described in Table 4.6. The means for the pretest for both groups and the posttest for the control group range from 21 to 24. The median ranges from 19 to 21 for the pretest for both groups and the posttest for the control group.

Table 4.6: Measures of central tendency and dispersion

	Experimental group		Control group	
	Pretest	Posttest	Pretest	Posttest
Mean	23	51	24	21
Median	21	50	21	19
Mode	20	34	15	11
Range	33	39	34	30
Standard deviation	7.3	11.1	8.2	8.0

Source: Author's own, 2010.

This narrow range in the data distributions confirms that without an intervention of the kind represented by the independent variable the pretest and the posttest as proxies for technological literacy are challenging to the professionals sampled. But it also shows consistency in performance, and hence in evaluation, upon the same tests. Pending further analysis, the median for the posttest for the experimental group can be postulated to represent the effect of the exposure to the functionality grid upon the performance of the participants as a measure of technological literacy.

As the value which occurs most frequently in a distribution, the modes for the four data sets from the pretest for the experimental group to the posttest for the control group are respectively 20, 34, 15 and 11. The data sets are, however, small and not much insight can be gained from this indicator.

The range for the pretest for both groups and the posttest for the control group starts at 30 and ends at 34, with the range for the experimental group's posttest found at the anticipated higher level of 39 percentage points. According to Cryer and Miller (1994: 86), the range suffers from the same problem as the mean in that it is sensitive to outliers. In fact, it is a description of the most extreme observations in the data distribution. But two data sets with the same means can have vastly different ranges, which makes the range a good measure of variability in the data set. The ranges for the different data sets are nevertheless a further indication of stability in both the experimental mechanism and method.

According to Cryer and Miller (1994: 93), the standard deviation measures variation around the mean of the data set. In the final analysis, therefore, the standard deviations for the three data sets without an intervention range from 7.3 to 8.2. Although the data distribution for the experimental group's pretest has a higher range than the control group's posttest, its lower standard deviation of 7.3 is therefore an indicator of less spread around its mean. Another reason for the differences between the standard deviation of the experimental group's pretest and those of the control group is the sensitivity of the standard deviation to extreme observations. In this instance the range of nine percent is found between the second highest and the highest scores for the experimental group's pretest, and a range of 10 percent is found in both tests for the control group.

The trends and patterns described above indicate a clear, and observable, difference in results between the experimental group and the control group for the posttest. The difference from pretest to posttest between the control group and the experimental group can clearly be seen when plotted on a scatter plot. Figure 4.8 shows the results of the pretest and the posttest for the control group, and Figure 4.9 shows the same values for the experimental group.

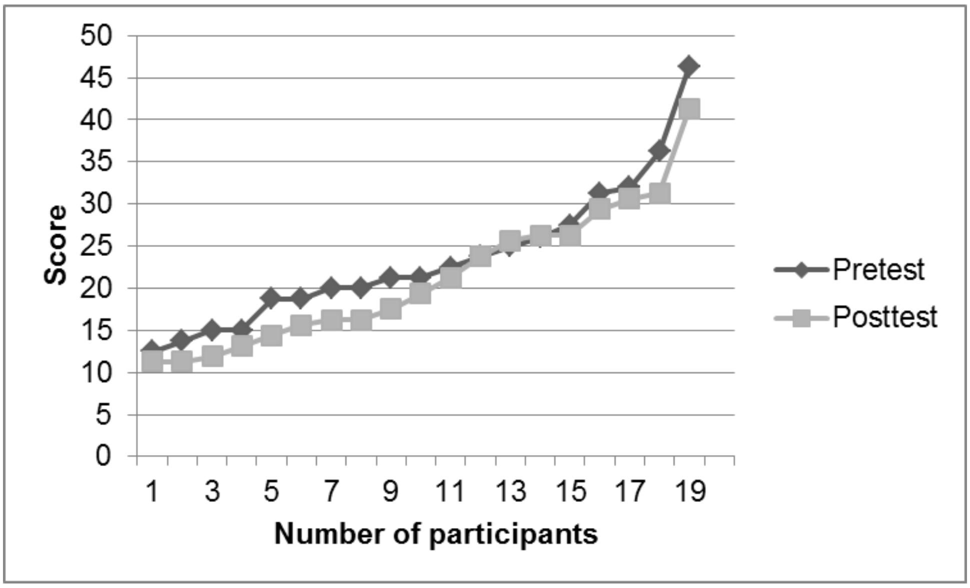


Figure 4.8: Scatterplot of pretest and posttest scores for the control group

Source: Author's own, 2010.

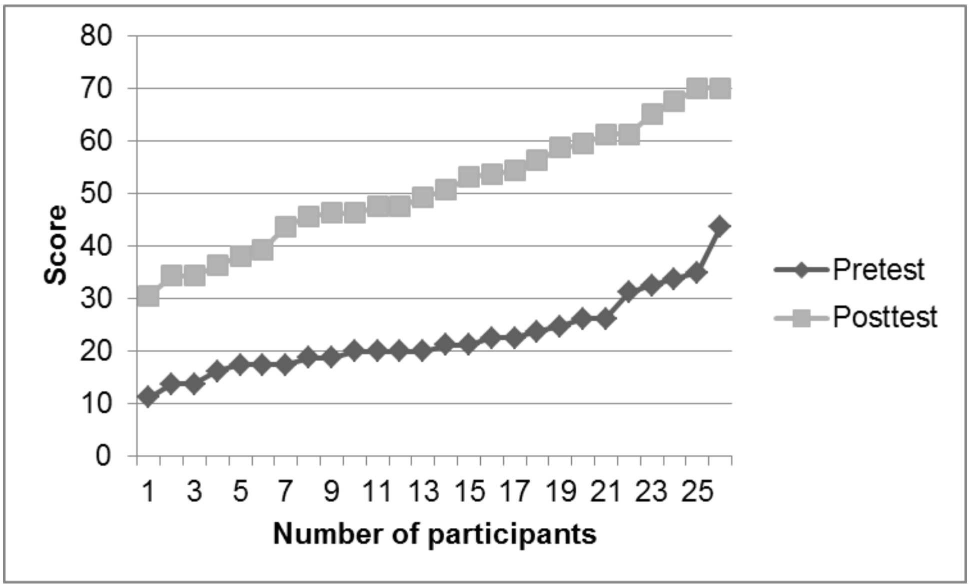


Figure 4.9: Scatterplot of pretest and posttest scores for the experimental group

Source: Author's own, 2010.

More precise analysis is required to test the subsequent assumption of causality between the functionality grid, as independent variable, and technological literacy as dependent variable – keeping in mind that the construct of technological literacy is represented by the proxy of a test score in all the tests, but the assumption of causality only applies to the test score of the posttest for the experimental group. The next section describes the procedure followed for a test for causality on the results.

4.4.5.2 Testing for causality

Doncaster and Davey (2007: 1) describe analysis of variance (ANOVA) as a "…powerful statistic and core technique…" for testing causality. ANOVA determines the influence of a factor of interest upon the variation in the magnitude of a response variable. In this instance, the functionality grid is hypothesised to be the specific factor of influence upon the test scores for the posttest in the experiment. Indeed, according to these two authors, ANOVA comes to its fullest right when used for hypothesis testing. The outstanding strength of ANOVA, according to Doncaster and Davey (2007: 2) is its capacity to distinguish effects on a response variable from many among several different sources of variation, or time. A further benefit of particular interest to this experiment is the fact that ANOVA provides for the analysis of variance to compare results of two groups where these groups are not of equal size (Cryer & Miller, 1994: 523).

The null hypothesis for this study holds that the functionality grid does not enhance MOT practitioners' technological literacy. The research question investigates whether the functionality grid does enhance technological literacy. Due to the nature of this research question, a statistical test is required to properly measure the sample of participants repeatedly over time, or then at least once before application of an intervention as experimental treatment, and at least once after application of the intervention. The researcher wants the best test to assess the strength of his research assumptions, and indeed Girden (1992: 4), Rencher (2002: 204), and Doncaster and Davey (2007: 179) describe the Repeated Measures ANOVA as the most appropriate test for the above purposes. According to Girden (1992: 4), Repeated Measures have been applied in almost all behavioural and social sciences, including psychology, political science, economics as well as business science. The participants in the experiment participate as subjects in more than one level for a factor which undergoes intervention, and are then measured repeatedly on that factor. Hence the term “repeated measures”.

In consultation with the Centre for Statistical Consultation at the University Stellenbosch, a mixed model Repeated Measures ANOVA was therefore resolved to be the most appropriate statistical test for causality in this experiment. The results of this statistical test show that the null hypothesis is rejected in favour of the alternative hypothesis that the functionality grid enhances MOT practitioners’ technological literacy. In fact, as depicted in Figure 4.10, the results are highly significant.

In Figure 4.10, it is demonstrated how the percentage score for the experimental group shows a significant increase from the mean of 23 for the pretest to the mean of 51 for the posttest, while that of the control group experiences a slight decrease from 24 to 21. So, there is over time a significant increase in the dependent variable due to the variation in the level of the independent variable. In other words, when the lecture about the functionality grid is applied as the intervention, the experimental group’s score for technological literacy shows a significant improvement on the pretest benchmark, whereas the score for the control group shows a slight decrease. As a result, causality is confirmed between the functionality grid and technological literacy.

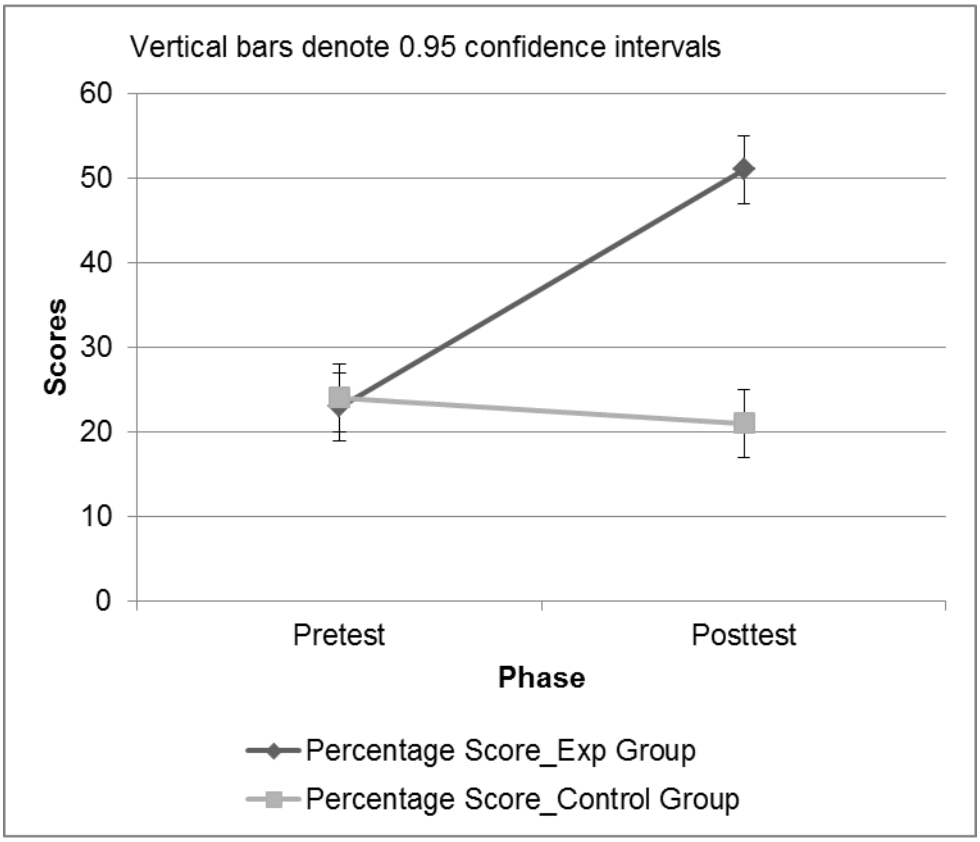


Figure 4.10: The interaction between time and group

Source: Author's own, 2010.

More certainty is however required in order to make sure that the researcher does not erroneously reject the null hypothesis if it should not be rejected. To this end, it is best to show step by step the interaction between the means of the experimental and the control group over time. Consequently, the sub-hypothesis of no difference between the means for the control group's pretest and the experimental group's pretest is accepted at a p-value of 0.763. Similarly, the sub-hypothesis of no difference between the means of the control group's pretest and posttest is accepted at a p-value of 0.349. Against this, the sub-hypothesis of no difference between the means of the control group's pretest and the experimental group's posttest is rejected at P<0.001. Importantly, the sub-hypothesis of no difference between the means of the experimental group's pretest and the experimental group's posttest is rejected at P<0.001, and similarly so for the means of the control group's posttest and the experimental group's posttest at P<0.001.

The p-value can be seen as the probability that the null hypothesis is rejected in error where relevant in the above sub-hypotheses. At 95 percent confidence limits the p-value is set at 0.05, allowing for a five percent chance of error for this test. But even when set at the level of 0.01, or one percent, these results remain highly significant at a consistent p-value of 0.000. The net result of these steps is that H^0 of no relationship between the variables is rejected and H^1 is accepted. The functionality grid in fact does enhance MOT practitioners' technological literacy.

4.4.5.3 Contribution to the hierarchy of outcomes

From the main quantitative experiment the following impact on the hierarchy of outcomes can be reported. First, from the comments of participants there is a discernible impact on the mindsets of participants. These views are consistent with the results of earlier tests, but because of the quantitative nature of these tests it is difficult to judge qualitatively the degree to which an ACE mindset is encouraged. Second, the majority of participants report an improvement in technological knowledge. Third, as can be expected, there is strong evidence of improvements in technological literacy. After exposure to the functionality grid, participants were able to work comfortably and confidently in tasks that involved the organisation of technological information. Statistically speaking, the level of competence in these skills was significantly higher than the levels of competence of participants who were not familiar with the functionality grid.

4.5 THE DUAL-NATURE EXPERIMENT

4.5.1 Introduction

At the heart of this final experiment lies the research question of whether the functionality grid can still be seen to enhance MOT practitioners' technological literacy when measured with a dual-nature experiment which comprises of tools from the qualitative research tradition. This experiment constitutes of two elements, a quantitative element and a qualitative element. The quantitative element evaluates the impact of an educational intervention on technological literacy, while the qualitative element probes the impact on the mindset and on the technological knowledge of participants. The following discussion presents first an overview of the preparation for this exercise, and then an overview of the final implementation phase. The final section describes the outcomes.

4.5.2 Design considerations

This experiment is intended to combine tools associated with semi-qualitative research with existing techniques in order to observe and assess whether the functionality grid enhances the MOT practitioner's technological literacy. This specific research question arises from the hierarchy of outcomes which was developed during the previous two empirical exercises. This approach assumes that the functionality grid as paradigm creates a positive and enlightening mindset upon technology, and therefore it must be assumed to increase technological knowledge and hence also to enhance technological literacy.

O'Cathain and Thomas (2004), as well as Brabin, Roberts and Kitchener (2007), offer useful guidelines on how to think about semi-qualitative data. O'Cathain and Thomas (2004: 26) point out that open questions require more resources for data input and analysis, because they have some of the attributes of a qualitative approach. Open questions allow the participant to tender an answer in his own words, with little or no structure imposed. Subsequent analysis hence requires some techniques associated with qualitative research. The typical open question is often, however, without any useful context when it appears in a survey. The researcher should therefore already during the research design allow for a technique which elicits thoughtful responses from the respondent, also to serve as a safety net for catching complimentary perspectives, according to O'Cathain and Thomas (2004: 27).

Brabin *et al*. (2007) demonstrate the use of a semi-qualitative data analysis process complimenting a larger quantitative study on which they have reported earlier. They mention specifically that they intended the semi-qualitative approach to generate insights not conveyed by their quantitative data. But two significant limitations apply, viz. low response numbers make for a lack of external validity and the semi-qualitative nature of the approach makes for a lack of the real detail in response and analysis associated with full qualitative approaches (Brabin *et al*., 2007: 24). They nevertheless find the compromise between these two traditional approaches as useful.

This experiment involves only two participants at a time. The experimental participant is subjected to an intervention, while the other participant serves as control. The intervention consists of a short summary lecture encapsulating the nature and the working of the functionality grid. The intervention is controlled and is followed by a short test designed to observe and assess whether the functionality grid enhances MOT practitioners' technological literacy. The combination of lecture and test delivered to the experimental participant is appended as Appendix 27.

With this exercise, the short test consists of a set of five technologies similarly described and meeting the same conditions is the case with the technologies selected for the pretest posttest experiment. The five technologies for this experiment are also randomly selected from the same list of technologies which serves as source for the main experiment. An example follows below:

Technology:

Nanoyarn

Description:

New Hampshire-based Nanocomp Technologies is weaving nanotubes into lengths of yarn that can be used for commercial applications. They have recently delivered a a nanoyarn of almost 10 kilometers to an aerospace company. Until now they have been too difficult to manufacture in useful quantities, but this breakthrough in form factor means nanotubes can be commercially supplied and used for the fact that they are hundred times stronger than steel and conduit both heat and electricity.

In this instance however, the tasks to be executed by the participant in the experimental role are contained in an initial set of instructions which is divided in two sections. The first section is meant to assess whether the shorter, and more practical orientated exposure to the functionality grid enhances technological literacy. In comparison to the four questions in the quantitative experiment formulated to evaluate technological literacy, this experiment consists of only two questions. The nature of the second section of instructions represents the dual-type nature of this experiment. It allows for recording of observations and impressions about the nature of the experimental process as well as of its constructs. These two sets of instructions appear below:

1. When you have completed your reading, proceed with following instructions. You have 60 minutes to complete this task.

    a. Study the descriptions of the five technologies which appear from P.4 onwards.

    b. Then describe the essence of each technology in one sentence only.

    c. Think of any classification scheme, and then show how each technology fits into your specific scheme.

2. When completed, exchange your results with your co-participant, evaluate his/her submission and proceed to answer the following questions. No time limit applies.

    a. Describe your co-participant’s submission. Does it resemble a classification scheme of one or another nature? Why do you say so?

    b. How long did it take your co-participant to complete the exercise, i.e. what would be a good estimate?

    c. From observing his/her behaviour, did you pick out any structure or systematic method in completing the exercise?

    d. Did he/she appear to be at ease during the exercise?

The control participant, once again, receives a placebo, appended together with the test as part of Appendix 28. In this instance, the placebo discusses the question of whether the Craig J. Venter

Institute's programme for the creation of synthetic life will be able to accelerate algae fuels. This remains a relevant topic, but it is also challenging and as such it is meant to oblige the participant to concentrate and to commit to the exercise. The same technologies, the same questions and the same instructions apply as in the case of the experimental participant.

4.5.3 Preparation

This experiment was planned to be small in order to create the opportunity for personal interaction between participants, and between the researcher and the participants. Its objective, design, structure and content all stem from experience gained in the planning and application of the first two methods in the data model. Sufficient insights had been gained by now about the general trend of the responses in the previous exercises. The researcher however remains the critical observer, putting challenges forward in order to subject the theory under observation to the most stringent tests possible within the set constraints of the study, and within the logical structure of the wider research strategy.

Insofar it concerns sampling of participants, the same principles applied. This experiment is also part of the theoretical field formation process. It is also meant to help form, expand, and anchor the theoretical field in MOT. It is applied research, and internal validity remains the priority. The same academic profile for participants to be selected for this experiment applied, i.e. post-graduate students with prior working experience. Permission to use the USB MBA cohort still applied. However, from experience gained with the previous experiment, and from personal discussions with MBA students, it soon became apparent that the "word had spread" and that the chances of convincing another set of student to participate were small. On the negative side was the fact that between 90 minutes and two hours were required to complete the entire sequence designed for this experiment. On the positive side was the fact that due to its particular nature, and role in the data model, a minimum of four and a maximum of six participants were required, making up two or three pairs each for execution of the experiment in accordance with Figure 4.11.

Given the participant profile required, and the fact that MBAs could not further be considered for participation, a decision was made to use the USB PhD cohort, all of whom were peers of the researcher. With three exceptions, all of 43 PhD students were part-time and spread across the globe. However, only two PhD students agreed to participate. More were willing but found themselves occupied with work, or in other countries.

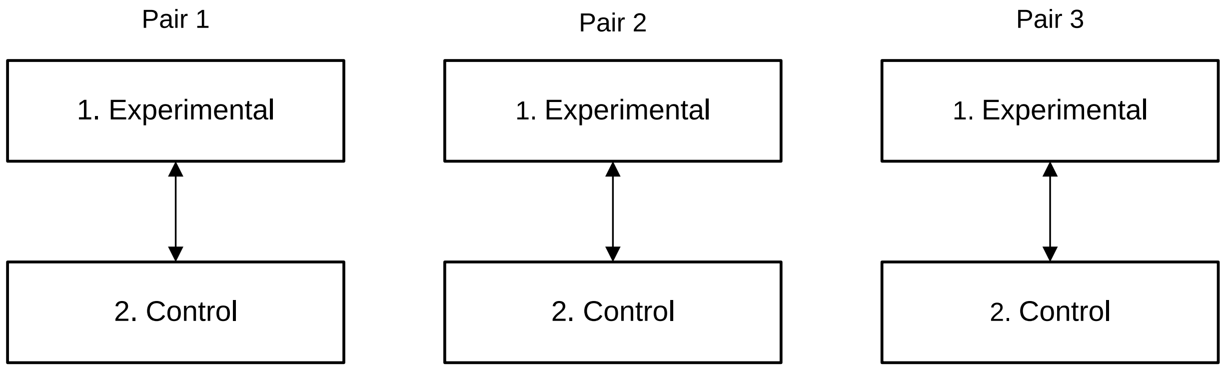


Figure 4.11: Configuration of participants for the dual-nature experiment

Source: Author's own, 2010.

One last option presented itself, which was to use attendees of the annual Doctoral Training Program (DRTP) for the Executive PhD at the USB. These attendees typically would have first and second degrees combined with work experience. Permission was hence requested to the coordinator of this course to make an appearance at the last session of the last day of the 2010 DRTP, and to request participation from prospective PhD students. This session took place on 17 September 2010 and from 58 attendees, 12 DRTP candidates agreed to participate. Knowing from experience that it would be difficult to have the minimum number of four participants organised for conducting the experiment, no limit was put to the number of participants who volunteered, and the contact details of every volunteer were accordingly recorded. This was an entirely random process, and the only condition which applied was that the experiment was to take place at the USB itself, thereby excluding attendees not based in Cape Town or in close proximity.

On 22 September 2010, a short message went out to all volunteers requesting them to confirm participation. Upon this request, 10 of the 12 volunteers replied. On 5 October 2010, these volunteers were asked to indicate whether they would prefer a Wednesday or a Saturday for conducting the experiment on site at USB, since the experiment in this instance was to be a paper exercise. At the same time, coordination with USB continued in order to arrange the breakaway rooms required for the experiment. Several days followed during which efforts to coordinate responses upon the proposed roster persisted. Although the volunteers were cooperative, it was difficult to gather more than four participants together at any one of the preferred dates and times, which also needed to be synchronised with the availability of the breakaway rooms.

While confirmations to those who had agreed to the two proposed dates went out immediately, the final decision to proceed with the six candidates who could be slotted into the programme was made on 10 October 2010. Following this decision, reminders went out to the final group of participants, all of whom confirmed participation.

4.5.4 Implementation

The participants were ready, the experimental material was ready, and the breakaway rooms were organised. Two pairs of participants were to conduct the experiment on Wednesday, 13 October 2010, and one pair on Saturday, 16 October 2010.

When meeting with the first four participants on Wednesday, 13 October, they were first randomly paired as they arrived for the event, and then randomly allocated through a simple toss of a coin to the experimental and the control role respectively. Participants were accordingly informed that the allocation was for the purposes of the experiment, but they were not informed that they each had a different intervention, i.e. the short lecture of the functionality grid to the experimental participant and the placebo to the control participant. Each pair was then allocated a breakaway room and inducted into the process to be followed. The sequence was to consist of an opportunity to read the instructions and to peruse the rest of the document, followed first by the 30 minute period to read the enclosed précis, then the 60 minutes to complete the questions about the five technologies and finally followed by exchange and evaluation of results. As per the second set of instructions, it was pointed out to participants that they have to remain aware of the co-participant's actions and conduct during the 60 minute exercise. Other control measures which applied were that no discussion was allowed between the participants and that the time limitations were to be enforced.

Conducting the experiment itself now followed. The 30 minute period proved adequate for studying the intervention, as did the 60 minute period for completion of the two questions each for the five technologies in the subsequent test. The breakaway rooms have facilities for unobtrusive observation, and the researcher could control and follow progress without needing to interrupt the experiment itself. Upon completion of the first two tasks, the participants were requested to exchange results and to proceed with the second set of instructions. No time limit applied and each participant was allowed to complete this task at his own time and pace.

With each pair having their sequence completed, a final task to complete was to ask each participant to write down his or her overall impressions about the exercise, and at the same time, to express in a short interactive discussion between the researcher and the two participants his or her concluding thoughts about the process. During this discussion, each pair was informed about the difference in roles and content, and the reason for this variation. This process was first completed for the one pair, and then for the other.

The typical duration for the full sequence as described above was two hours. In spite of this, the final short discussion had to be cut short. This final discussion was dynamic and elicited definitive views about the experiment, and the outcomes it pursued, from both pairs of participants. Given that they were prospective PhD candidates who at the time still had to ponder on the formulation of their research proposals, all participants without exception expressed a keen interest and appeared to have enjoyed the final discussion, and the enlightenment it brought about the nature and role of an experiment like this one. In particular, the objective and critical role of the researcher as outside and detached observer of the theory under observation, and the manner this role was applied in conducting a dual-nature experiment, enjoyed attention from both pairs of participants.

The above process and sequence were repeated in precisely the same manner for the final pair of participants on 16 October 2010. For the final interview, the same dynamics manifested, with the same sentiments expressed by the participants. The results were now in hand, gained with a random and controlled process. At this stage, seen from the researcher's perspective, the set of data, albeit small, had evolved to the point where it would fulfil the role designated to it as the third leg in the triangular data model. What the outcome of the experiment was, however, first needed to be described and analysed.

4.5.5 Discussion of the results

4.5.5.1 Methodological considerations

Bernard (2000: 437) presents a good overview of qualitative data description and analysis techniques. A selection of the most important guidelines he offers are listed and discussed below:

1. The researcher must remain the sceptical observer. This notion is derived from Popper's falsification principle. Brewer and Hunter (2006: 24) say about this principle that when during the test of a successful theory it is verified it only escapes disconfirmation. This is because scientific knowledge remains provisional, or contingent upon the results of future studies.

2. The researcher must look for consistencies and inconsistencies in data as they are collected and analysed. Welman and Kruger (2001: 184) suggest in this regard that the researcher searches in an inductive fashion for recurring patterns and consistent regularities. In other words, the researcher must ask himself the question of what other recurring themes are found as a general explanation for the patterns observed in the evidence of the case being examined.

3. If the possibility presents itself, the researcher should seek more objective evidence in order to corroborate the evidence already collected. At the same time, the researcher must be open to negative evidence and must equally record and test such evidence.

4. Hermeneutics, or then contextual interpretation, should be employed in order to continually understand words and their intended meaning in text or verbal content.

5. Grounded theory as an approach to identify concepts which arise from the data offers a viable set of techniques to link these concepts into substantive and formal theories. McAdam, Leonard, Henderson, and Hazlett (2008: 827) describe grounded theory as the "…theorization of data… encourages practitioner based insights and inputs". It is not to be the primary method in this study, but it appears at once as a good supplementary method to support the foundations of theory already present in this study, and fitting to the multi-method approach in the research design. In fact, Fassinger (2005: 157) earlier describes grounded theory as uniquely positioned to serve as a paradigmatic bridge between post-positivism, interpretivism and critical approaches to qualitative research.

4.5.5.2 Description and analysis

With the focus on the quantitative results, the test scores of three pairs of participants are listed in Table 4.7 in the sequence in which they completed the experiment. The average scores per group appear at the bottom of the table. In Pair 1, the random nature of this exercise makes for a practising pastor with an MBA as the experimental participant across a manager for strategy in the management team at the University of Stellenbosch, qualified with an M.Com in Organisational Psychology as the control participant. In the same sequence, Pair 2 constituted of a manager of an economic development unit in the public sector versus a marketing manager for a recycling startup. Pair 3 consisted of a former investment analyst who became a full-time PhD student across a university lecturer in Accounting. The final average result of 47 percent for the experimental group compares relatively well with the average of 51 percent for the experimental group's posttest in the quantitative experiment, considering that the experimental group in this instance had only a short and very limited exposure to the functionality grid. The 75 percent by the first participant does however have a major effect upon the average score, and the 20 percent for the lowest score is significantly lower than the lowest posttest score (31%) for the experimental group. On the other hand, the score of 75 percent compares well with the top score of 70 percent in the main experiment, if poorly with the top score of 90 percent in the pilot exercise. The lowest score of 20 percent for this exercise in turn compares well with the 15 percent achieved in the pilot exercise, also considering that a formal time limit was set for this final exercise whereas the pilot exercise had no time limit.

Table 4.7: Results of quantitative evaluation

	Experimental		Control	
Pair 1	75	MBA (pastor)	40	M.Com. (manager strategy)
Pair 2	20	M.Dev. Fin (manager - public sector)	45	MBA (marketing director, recycling start-up)
Pair 3	45	M.Com. (investment analyst, now full-time PhD student)	30	MBA (university lecturer - Accounting)
Average score per group	47		38	

Source: Author's own, 2010.

The highest score of 45 percent for the control group compares well with the highest score of 46 percent for the control group's posttest in the main experiment. However, the averages for the control groups in the two experiments compare poorly. The average for this experiment is 38 percent, against the 24 percent of the main experiment, explained by lower scores at the lowest ends, i.e. 13 percent, for the main experiment. Reasons for these patterns are however found in further analysis of information collected with this exercise, specifically with the questions posed in Section 3 of the dual-nature experiment and with the insights gained during the follow-up interview with each pair of participants. As a reminder, these questions are listed below:

1. Describe your co-participant's submission. Does it resemble a classification scheme of one or another nature? Why do you say so?

2. How long did it take your co-participant to complete the exercise, i.e. what would be a good estimate?

3. From observing his/her behaviour, did you pick out any structure or systematic method in completing the exercise?

4. Did he/she appear to be at ease during the exercise?

The combination of Pair 1 makes for a result of 75 percent against 40 percent. To the experimental participant, the control participant's submission took a while longer, but her submission did resemble an interesting classification scheme which may be useful. She also appeared very comfortable to him. In comparison, his submission appeared to her like a "…pre-decided criteria based on a principle…I don't understand it but it appears to be a classification scheme". His submission scored the highest, because he seemed to internalise very well the content of the intervention about the functionality grid. But he appeared frustrated to the control participant, and this is confirmed by his comments in the follow-up interview. He felt "constrained…and inhibited" by the framework offered by the functionality grid, but he felt also "safe" by having a guideline at hand. He experienced the framework "…almost was too complex to master in 30 minutes…", but he also felt that parts were missing. Most interesting is his final comment that as a pastor he moved away from the practice of classification as a life strategy. From the control participant's perspective, the placebo was interesting and she enjoyed having to sum up the essence of each technology, as her work involves evaluation of business proposals. She had the "suspicion" that the experiment requires comprehension and understanding, and she enjoyed the exercise for its challenges and for its opportunities to interact and to reflect with respectively the co-participant and the researcher.

In Pair 2, the experimental participant saw that the control participant's submission resembled a classification scheme, and the control participant appeared comfortable as well. The control participant however saw no classification scheme in his counterpart's submission, even if the experimental participant appeared comfortable and completed the exercise approximately 10 minutes quicker. The experimental participant did however not benefit from the intervention, and in fact he did not use the functionality grid at all for classifying the technologies as per Instruction 2.c in the experimental material. His poor score underlines these observations. In comparison, it becomes clear from the follow-up interview that the control participant used what he remembers about the functionality grid from a lecture he attended in which the functionality grid appeared as a framework for analysis and understanding of technological innovations. The lecture formed part of a *Leaders' Angle* series presented by the Alumni Association of the USB, in which capacity it was attended by the control participant. As a result, his submission scores higher than that of the experimental participant, for whom the short intervention had no benefit even if he felt so from his comments afterwards, and even if he thought he had mastered the learning material. Apart from his attendance of said lecture, the control participant in fact also revealed afterwards during the concluding interview that he continues to use the functionality grid in his work as marketing director for a start-up company in the recycling business. For this experiment, of course, he had a placebo which made him feel a bit "lost". His concluding comments that the experiment is interesting and stimulating underlines the message consistently forthcoming from those participants who appear to become interested in the functionality grid and similar frameworks for conception and application in complex thought processes. It is worthwhile quoting his final comment: ”Classification is very important from a practical point of view to explain what you want to do”.

In Pair 3, the results are interesting when analysed in the context of the supplementary information. The experimental participant used the insights gained from the intervention, but he did not fully complete the exercise during the time allowed. His submission does though represent structure from his co-participants' perspective. His co-participant commented how he classified his technologies in terms "…of two variables, function and effect (called outcome)". He also appeared comfortable to his counterpart. In his final comments, the experimental participant also refered to the functionality grid as a "…easy frame to understand each new technology and to classify them into the different area". The control participant did not use a sensible framework and his submission does not resemble any structure to the experimental participant either, even if no discomfort was observed on the control participant's part. They took the same time to complete the exercise. In his final remarks during the interview the control participant realised that prior exposure, i.e. the intervention about the functionality grid, helped the experimental participant and made for the structure he saw in the latter's submission, and that his lack of knowledge "…didn't really help to explain / understand the technologies".

With reference to the hierarchy of outcomes, this experiment corroborates the outcomes of the first two tests. Knowledge of the functionality grid, even when acquired through a very short exposure to the functionality grid, changes the mindset of the participant in the direction of an ACE mindset. There is also evidence of increased technological knowledge in the comments of the participants. And finally the majority of participants exhibit an increase in technological literacy when tested.

4.6 COMPLYING WITH THE EMPIRICAL REQUIREMENTS FOR PARADIGMS

4.6.1 Closer inspection of the findings

The data collection sequence is now completed. With the results of all three exercises available, the following section offers further insights into the empirical findings.

The results of the semi-structured interviews show that the functionality grid makes a positive and lasting impact on MOT practitioners' mindset insofar it concerns technology understanding and exploration. From the sceptical observer's perspective, it is difficult to find a fault line in the arguments posed by the interviewees of how they became convinced of the empirical merits of the Functionality theory. At least with four of the five interviews there is supplementary evidence outside the researcher's domain which validates the submissions by these interviewees. An indication of how the ACE mindset manifested is the fact that the interviewees recognise the difficulty of understanding the future of technological innovations and they knew how to look for macro trends. They also showed that they understand the macro trends of technological progress, and the panoramic or macroscopic perspective required to make sense of these trends. With a single exception, the interviewees have shown resilience in their respective quests to understand technological progress and to harness it for the better. To this end, of course, they share two meaningful characteristics. First, they all have had the benefit of advanced degrees, and it can be argued therefore that they have had the intellectual and academic wherewithal to recognise the potential of the functionality grid when they got introduced to the theory, and to critically analyse this theory for its potential value in comparison to its contesting alternatives. They were, after all, under no obligation to apply the theory in their professional environments. Secondly, after introduction they all have had the opportunity to learn more about the functionality grid and to undergo a formative process insofar it concerns their impressions about this theory. Their descriptions of how they have changed their thinking after introduction to the functionality grid, and their subsequent views about the theory, are clearly corroborating each other's. But they found themselves in widely different industries, had no professional ties with each other, and did not have the opportunity to reflect with similarly inclined individuals or special interest groups about the application of the functionality grid as a solution for technology exploration. Clearly, the potential of the theory offered a strong appeal to them and convinced them to use it.

This, of course, is not necessarily in line with how a contesting theory ascends to paradigm status. On the contrary, sharing and debate form an important avenue for promotion of a theory as exemplary solution within a profession. Upon reflection of his use of the term "paradigm", Kuhn (1970a: 175) states the one way it is meant to be used is to stand for "…the entire constellation of beliefs, values, techniques, and so on shared by the members of a given community". On the other hand, even if the interviewees were not participants in this discussion, there is ample evidence of open forum discussions about a fundamental structure for technology, in which "frameworks" such as the functionality grid were widely discussed. One such example is the now closed Management of Innovation and New Technology (MINT) forum, which was followed up by the IAMOT forum.

Application of the functionality grid to physiology deserves more attention. In this instance, the medical doctor turned lecturer in Kinesiology, Human Physiology, and Exercise Physiology submitted that "James Miller developed a much larger biological matrix model in the 1970's but it was too large and too complete to be versatile. The 9 cell matrix is sufficient, adaptable [sic] and therefore a useful conceptual tool". The functionality grid can be seen here to be put forth as a better solution than an incumbent solution in the medical science. It has been tested as a solution between rival theories, and in this instance the practitioner is clear about the result in favour of the functionality grid. But he has been modifying the theory and changing its terminology for these purposes. This is therefore an atypical application of the functionality grid. In the view of this author this application compared to others brings complications to the work been done to consolidate the theoretical foundations of the theory for the purposes of MOT and its body of knowledge. A simplified and streamlined structure and symmetrical development of the theory and its applications would best serve to help solve the problem in the discipline. There are however contesting views to those of the author. Skyttner (2001: 90), for example, states that models are employed to develop new knowledge, to modify existing knowledge, or to give knowledge new applications. This application of the functionality grid, even if atypical, appears as if it does all of these. It develops new insights into physiology, it modifies existing knowledge by depicting such knowledge in a better manner with the symbols of the functionality grid, and it serves as a new application as well.

In the above regard it is worthwhile to again quote Kuhn (1970a: 46) when he writes that "A new theory is always announced together with new applications...without them it would not be even a candidate for acceptance". As is the case with the MIT work by Magee and De Weck (2004), the physiology application of the functionality grid can be concluded to make of this theory more of a paradigm, in fact promoting it across disciplines, in Kuhn's words, as "…a candidate for acceptance…" among contesting theories.

Concluding the results of the semi-structured interviews, application of the functionality grid is not incidental, nor so the news from various sources of its application. Word spreads about applications and outcomes. This is typical paradigm behaviour, and as was shown earlier, is clearly described as such by Kuhn. Limited evidence about an exemplary solution which gradually comes to the fore also fits Kuhn's description perfectly. At yet a deeper level, such evidence shows the theory at work ontologically. In turn, worldviews dictate knowledge, which grows via theory and is applied in practice. Practice ultimately creates more knowledge and insight, and feeds back into theory and epistemology to strengthen worldviews, as is proven within the limited space of this first empirical exercise. Insofar it concerns the hierarchy of outcomes, the evidence is clearly in favour of the formation of the foundational layer of this hierarchy. Thanks to its paradigm merits, the functionality grid makes a positive and lasting impact on MOT practitioners' mindset insofar it concerns technology understanding and exploration. It helps MOT practitioners to develop the ACE mindset. Evidence is also provided that the functionality grid leads to an improvement in technological knowledge.

With the outcomes of first the pilot study and second the main experiment which followed afterwards, further evidence is offered of a noticeable impact on the mindsets of participants, followed by an improvement in technological knowledge and ultimately a measured enhancement in technological literacy. Put formally, when subjected to an appropriate statistical test for causality, the functionality grid is confirmed to precede as cause the increase in the test score for the experimental group, where this test score represents technological literacy. This is an important finding, because a theory must be confirmed to have the mechanics of a theory. It must be confirmed to embody a relationship between observable units, or approximated constructs, in the real world. Bacharach (1989: 512) offers the modern view upon the Popper standard when he states that a theory is not a theory if it is not testable, no matter how profound it appears. The results of this test must therefore be seen in the context of the controlled and experimental conditions under which this particular experiment was conducted, including meeting the requirements of respectively randomness and the presence of a control group in order to minimise the chance of a confounding variable impacting upon the results.

Looking with a wider lens at these results, the average posttest score of 51 percent for the experimental group compares relatively poorly with the average score of 58 percent for the pilot exercise, considering that the final experiment was refined from the insights gained during the pilot exercise. But in comparison to the participants in the pilot exercise, the participants in the final experiment had to spend their scarce time on a pretest and a posttest which together involved an analysis of 15 technologies, whereas the pilot constituted of only five technologies. Less time typically means more pressure and the possibility of lower scores. Furthermore, the pilot exercise had more participants than the two tests in the final experiment, as well as a much higher top score of 90 percent. The top score was, however, achieved at the cost of time for the pilot participants as confirmed by these participants themselves, and time clearly was the one commodity not available to the participants in the final experiment.

Ultimately, it is submitted here that these results are generated in a well-controlled experimental environment and with tools designed for the job, which combined make for the internal validity of the conclusion that the functionality grid does indeed enhance MOT practitioners' technological literacy. This was, however, a first formal test of the functionality grid under experimental conditions. On this occasion, it weathers scrutiny and passes the test, but from Popper's perspective, this can also be seen as the theory merely escaping disconfirmation during this round. Hence, the final experiment with its own unique dual-nature approach.

The third exercise has a smaller base, but offers a more intense perspective upon the workings of the functionality grid. From the results it immediately becomes clear even a short exposure to the functionality grid inclines participants towards an ACE mindset. Insofar it concerns technological knowledge and the subsequent formation of technological literacy, in two out of the three pairs those participants with exposure to the theory score higher than those with no exposure in the tests. In these two pairs, the experimental participants in fact score meaningfully higher than the control participants. This fact offers increased evidence of technological literacy, corroborated by the comments of participants that they have experienced an improvement in technological knowledge. With the third pair, the trend is inversed, because the control participant scores higher as a result of previous exposure to the functionality grid, and as a result of the fact that the experimental participant seemingly did not benefit at all by the presentation, or by the logic, of the functionality grid.

From the supplementary information gathered during this exercise, the degree to which the experimental participants benefited becomes clearer. The submissions from the two experimental participants do resemble a clear classification scheme to the control participants when they subsequently evaluate these submissions. One control participant sees a set of predetermined criteria based on a principle, and the other sees two axes of which one is for function and the other for effect, or outcome. Both these observations match the logic of the functionality grid. In the case of the third experimental participant, his submission obviously resembles no classification scheme, an observation which matches the fact that he did not understand the functionality grid and could not apply it. On the other hand, however, this experimental participant sees in the control participant's submission a classification scheme and understanding of technologies. Responses to the question as to whether the participant observed structure and systematic behaviour synchronise with these answers. Structure and systematic thought are found where the theory is applied, and not so where the theory is not applied.

Looking into the final responses, the pastor has made a life decision to move away from classification and his frustration from confrontation with the set parameters of the functionality grid becomes clear. This is an understandable and very interesting response, and it shows how efficient the application of the theory can be upon exposure to its logic, even from someone with strong convictions against classification. At the same time, the opposite is true for the control participant in the first pair. She likes classification and uses it in her work in strategy management. Even if she had had no exposure to the functionality grid, she does relatively well in the evaluation of technological literacy. Similarly, the control participant in the second pair sees classification as an important method in his work, and the experimental participant in the third pair comments that the functionality grid makes for an easy framework to understand technology. The pattern becomes easily identifiable, and it follows a clear cause and effect relationship. Where participants have the opportunity to learn and apply the functionality grid, it generally enhances technological literacy. In most instances, even among the control participants upon exposure to its logic in the concluding interviews, the functionality grid generates positive sentiments.

This dual nature of this experiment creates a stimulating discussion and it presents the opportunity to critically evaluate the impact of the functionality grid. It offers equal opportunities for contrasting views, and in this instance at least it makes for counter-intuitive results thanks to its randomness and the controlled environment in which it takes place. The overall evidence is very clear that the functionality grid contributes to the full hierarchy of outcomes, even when observed and assessed with the toolset afforded by the qualitative research approach.

4.6.2 Adjudication of compliance

The final step in this sequence of practical exercises is to compare the results of the data collection and analysis processes with the empirical requirements of paradigms as listed in Chapter 2.

The first requirement involves accuracy. The triangulated data model created in this chapter helps to demonstrate how the hierarchy of outcomes is corroborated with every one of its three exercises. Where weaknesses exist in any of the individual methods, the next method compensates thanks to the triangular nature of this design. These methods have the same ultimate objective, and they supplement each other in pursuance of that end goal. With specific reference to the hierarchy of outcomes, it becomes clear from these exercises that the functionality grid creates an ACE mindset, that it helps to improve technological knowledge and that this theory ultimately enhances technological literacy.

The second requirement involves consistency as measured by internal and external validity. The procedures followed in order to ensure process control and quality of outcomes, as well as the laboratory-like settings in which the two experiments were conducted, help to ensure internal validity of the results forthcoming from these exercises. The role of the pilot study in support of the main quantitative experiment deserves specific mentioning in this regard. Given the limited sample of the main experiment, and the subsequent lack of generalisation, the one empirical requirement which it does not unconditionally comply with is the one listed thirdly, i.e. external validity. In spite of this serious limitation, however, the general diversity and randomness in the professions of participants in all the exercises, and the omnipresence of second degrees such as MBAs among participants deserve mentioning, because these attributes make for a diversity of authoritative views in the data collection process.

The fourth requirement involves simplicity, systematic structure and coherence. From the information gathered with the semi-structured interviews, and from comments and results forthcoming from the two laboratory-like experiments, it becomes clear that the functionality grid helps participants to confidently and competently order and organise technological knowledge.

Kuhn's fifth and final requirement involves productivity, requiring new predictions, relationships and hypotheses. Once again, the preceding chapter demonstrates how this theory complies with this requirement within the limited scope of this study. From the interviews, new applications of the theory are revealed. From the quantitative experiment, a clear causal relationship is established between the functionality grid and the enhancement of technological literacy, and from the dual-nature experiment further evidence is forthcoming corroborating this relationship. Confirmation is consistently found across all three exercises about the value of the functionality grid to MOT practitioners.

Finally, the set of semi-structured interviews and the dual-nature experiment both demonstrate how participants consider the utility value of the functionality grid within their own independent value frameworks. Allowing these frameworks to be described by participants themselves creates Kuhn's "reasonable context of persuasion", and allows for a wider setting in which the empirical attributes of the functionality grid are allowed to manifest so as to be described and to be assessed.

4.7 CONCLUSION

The research design for this study forms part of a broader research strategy which involves a theoretical analysis and a set of practical exercises which support each other. Where the theoretical analysis finds that the functionality grid presents a good fit to the paradigm template, and therefore meets with the theoretical requirements of a paradigm, the task left for further analysis is to seek practical evidence of whether this theory complies with the empirical requirements of a paradigm for MOT. This chapter describes the arguments for, and the systematic development of the research design in order to realise the set of objectives flowing from this particular task. From a post-positivistic research positioning extends a multi-method approach which results in a triangulated data model, which again ensures quality control of results. This model consists of a set of semi-structured interviews, a quantitative experiment and finally a dual-nature experiment. Combined, these three exercises are implemented in order to realise the hierarchy of outcomes conceived of in order to assess whether the functionality grid complies with the empirical requirements of a paradigm. The data collection process is subsequently described. This process started during January 2010 and ended during November 2010. The semi-structured interviews were the first of the three methods initiated. From this followed first the planning and execution of a pilot study which prepared the way for conducting the main quantitative experiment. Third in line was the dual-nature experiment. The results prove that the functionality grid complies with Kuhn's empirical requirements for paradigms. These findings supplement the findings made about this theory's theoretical merits as assessed with the paradigm template. It can be stated that in spite of the most stringent tests possible within the constraints of this study, the functionality grid indeed behaves as a paradigm for MOT. It contains therefore all the elements required to streamline and bring conceptual order to MOT and its body of knowledge. It offers to MOT all the qualities of a theory complying with the theoretical requirements as well as the empirical requirements of a paradigm.

CHAPTER 5
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter presents a summary of the research process. It starts with the problem description and then offers a review of the overall research strategy and the set of considerations which determined this strategy. Next follows a summary of the theoretical analysis as the first phase of the research strategy and the empirical design as the second phase of the strategy. A review of the results of these two phases is presented in the penultimate section. The final concluding section offers a submission regarding the academic and management implications of the study.

5.2 A REVIEW OF THE PROBLEM STATEMENT AND THE RESEARCH PURPOSE

It is fair to comment that the link between technological progress and economic growth is self-evident. MOT is the one discipline best positioned to help society capture the technology-based innovation opportunities associated with technological progress. Yet, the discipline lacks a clear conceptual foundation, which again weakens the consolidation and expansion of the MOT body of knowledge and which ultimately contributes to the general lack of technological literacy found manifested in society. This means opportunities to leverage technology-based innovation opportunities are not optimally leveraged, which causes lower economic growth.

The root of the problem can be found in the diversity of views about the structure of the conceptual basis to serve as foundation for MOT. This diversity manifests among others in contesting templates towards the MOT body of knowledge. As a result, the discipline is described as directionless, and in need of a unified model. The problem is clearly identified. MOT cannot pursue its task of educating professionals about technology-based innovation opportunities, and it cannot guide technological progress to the benefit of stakeholders and the triple bottom line, unless the discipline finds conceptual coherence and order. The debate about the theoretical merits of the discipline has to find direction, and agreements have to be forthcoming about its underlying conceptual foundation. Upon such agreements should follow a consolidated and dedicated MOT body of knowledge. Conceptual clarity brought to these key foundations will help to reconfirm the discipline’s role as custodian of the proficiencies required to manage technology.

Following from the problem statement, the aim of this study is to help formalise and streamline the conceptual foundation for MOT by assessing whether the functionality grid complies with the requirements of a paradigm. This research therefore sets itself the task of exposing the nature of this theory as a contesting theory and determining its compliance first with the theoretical requirements of a paradigm, and second with the empirical requirements of a paradigm.

From the aim follows the research objectives for this study. These objectives comprise of a sequence which involves an overview of the Kuhnian paradigm discourse, after which follows first the construction of a paradigm template which represents the theoretical requirements of paradigms, and second the identification of the empirical requirements of paradigms. Next in the sequence follows the fitting of the functionality grid to the paradigm template in order to assess whether this theory complies with the theoretical requirements of a paradigm for MOT, and then the practical exercises designed to assess whether the functionality grid complies with the empirical requirements of a paradigm for MOT. A final objective in the sequence is the formulation a set of recommendations for the field of MOT and its community of practitioners.

5.3 A REVIEW OF THE RESEARCH STRATEGY

This study primarily represents a contribution to field formation in MOT. It comprises basic research which is intended to make a theoretical contribution to the fundamental conceptual nature of MOT. But it also constitutes of empirical research. As a result, the research strategy reflects this duality in two phases, respectively a theoretical evaluation of whether the functionality grid complies with the theoretical requirements of a paradigm, and a practical evaluation of whether this theory complies with the practical requirements of a paradigm. The second phase is grounded in the post-positivistic research tradition, which helps to justify the presence of qualitative and semi-qualitative data collection and analysis techniques, and which helps to produce evidence not possible from within the conventional logical positivistic tradition.

To deploy these two phases within a sensible context to the student of Economic and Management Sciences, the introductory chapter explains a number of key concepts which make for the practical market ecosystem in which MOT finds application as a profession. These concepts are also found in the unfolding of this study. Among them are notions such as technological literacy, the technology investment strategy, technology tracking and selection, and a comparison of inventions with innovations.

5.4 A REVIEW OF THE RELEVANCE OF THIS STUDY

The relevance of this study is found in four related and practical features of contemporary society. Techno-economic ecosystems explain the linkage between technological progress and economic growth. Technological progress, in its turn, is typically analysed in accordance with the main characteristics of the incumbent technical epoch. The current epoch is characterised by the convergence of nanotechnology, biotechnology and information technology. This epoch offers new technologies which must be understood for their distinctive attributes from among competing technologies representing elements on a broader technological landscape. Yet society in general lacks technological literacy, and this deficiency is particularly prominent in the developing world. Given the above scenario, helping to streamline and bring order to the conceptual foundations in MOT with a theory towards systematic technology thought makes this study a highly relevant exercise.

5.5 A REVIEW OF THE OPERATIONALISATION OF THE RESEARCH STRATEGY

5.5.1 The theoretical analysis

The first phase of the overall research strategy pursues three research objectives which constitute a theoretical analysis. This analysis involves two academic constructs, i.e. scientific paradigms and the functionality grid. The notion of paradigms originated with Kuhn's exposition of the structure of scientific revolutions. The central element in these scientific revolutions is paradigms, and they have since evolved to become a fundamental notion in the philosophy of science. It becomes clear, however, that the nature and role of paradigms need a review for the purposes of this study. Not only is more clarity required about the definition, or a practical description, of paradigms, but also of its role in everyday science and everyday business. As a result, this theoretical analysis offers a deconstruction of the notion, from which follows reconstruction in the format of a paradigm template. The purpose of the paradigm template is to generate a set of guidelines in accordance with which the functionality grid is to be evaluated for its compliance with the theoretical requirements of a paradigm. As a final step in the theoretical analysis, this assessment is described.

From the deconstruction of paradigms, their composition and the role of each of their components in their functioning become clear. Accordingly, the ontological layer serves as the guide to assess the most basic and foundational theoretical principles of the paradigm under examination; the epistemological layer serves to guide the analysis of epistemological claims by the paradigm under examination; the layer of theory and models serves to guide knowledge creation; and the final layer of the paradigm template consists of methodologies and practices. The paradigm, ultimately, functions as a whole, with each component important in its own right, but with each making a contribution to the whole so that it projects influence stronger than the sum of its parts. The paradigm template is next constructed in order to set the genetic sequence of a paradigm.

With the evaluation of the functionality grid's fit to the paradigm template, each layer is critically analysed for the theory's compliance to the sequence set by the template. The results show that the functionality grid actually contains all the components of a paradigm. The evaluation shows that the theory is based on firm ontological foundations, and that it makes a substantive epistemological contribution to the MOT body of knowledge. The functionality grid is furthermore shown to have embedded into its DNA a substantive conceptual structure, with simple and easy rules for practical application, and with accessible symbols which make understanding and learning of its applications and results accessible to MOT practitioners. These observations also signal that the functionality grid displays the full complement of theoretical requirements associated with a paradigm.

More than merely evaluating how the functionality grid fits to the paradigm template, and how it complies with the theoretical requirements of a paradigm, this analysis also proves the durability and the longevity of paradigms. It demonstrates how the intellectual currency of paradigms can be exchanged for practical application to the good of science and practice. It also helps, and raises expectations, for further debate. It is, after all, true that the appearance of a real *coup d'état* leads to much contemplation and debate after the fact. At least in academy, such debate can be had, in the true tradition of the Kuhnian discourse, about the merits of the paradigm template, and about the merits of the evaluation of the functionality grid's fit to the paradigm template. With the results of the theoretical analysis allowing for more direction, such debate can be had to the benefit of the discipline of MOT and the profession it constitutes of.

It follows from this analysis that complying with the theoretical requirements of a paradigm the functionality grid must be assumed to make a durable impact in the profession of MOT, and especially upon the MOT practitioners who pursue this profession. So the next phase of this research strategy is to formally evaluate with the practical exercises whether the functionality grid complies with the empirical requirements of a paradigm.

5.5.2 The practical analysis

The review shifts now towards the second phase of the overall research strategy, involving the practical steps taken to determine whether the functionality grid complies with the empirical requirements of a paradigm. The research design which subsequently evolves pursues a hierarchy of outcomes which incrementally demonstrates how the functionality grid complies with Kuhn's empirical requirements for paradigms. Consequently, it makes provision for multiple testing methods combined in a triangular data model. This kind of data model is known for the opportunities it creates for cross-validation and cross-fertilisation of research procedures, findings and theories. It costs more effort, but using it leaves less opportunity for rival hypotheses to alight and to dilute the validity of the research findings. At the same time, this approach serves as a manifestation of the post-positivistic research tradition, combining elements of the traditional hypothesis testing deductive approach with elements of the qualitative research tradition. Exactness of precisely designed statistical instruments is combined with a deeper and a behind the scenes analysis of contributions from research participants. The result is a wider front along which the functionality grid is subjected to testing and subjected to assessment of its empirical merits. The three legs of the data model consist of a set of semi-structured interviews, a quantitative experiment and a smaller dual-nature experiment.

5.5.2.1 The semi-structured interviews

The purpose with the semi-structured interviews is to examine the research question of whether the functionality grid makes a positive and lasting impact upon MOT practitioners' mindset insofar it concerns technology understanding and exploration. These interviews are held with MOT practitioners who are known to have had the opportunity to learn about the functionality grid and have subsequently used the theory in their professional capacity. The data forthcoming from these interviews is analysed with techniques associated with the qualitative research tradition. The findings are offered in the format of the hierarchy of outcomes. Accordingly, this first exercise offers firm confirmation of the impact of the functionality grid upon participants' mindsets, from which follows a discernable and significant improvement in technological knowledge as reported by the participants themselves. Although no conclusion can be made about technological literacy, as this outcome did not form part of the exercise, encouraging signs are found of how the functionality grid manifests as an ascending paradigm among the participants in this first exercise.

5.5.2.2 The quantitative experiment

The functionality grid makes a positive and lasting impact upon MOT practitioners' mindset and it creates technological knowledge. The contribution of the quantitative experiment is meant to statistically test whether at the highest level of the hierarchy of outcomes technological literacy may be enhanced by the functionality grid. Following a hypothesis testing deductive approach, the construct of technological literacy is made to serve as the dependent variable against the functionality grid, which becomes the independent variable. The null hypothesis consequently states that the functionality grid does not enhance MOT practitioners' technological literacy. The alternative hypothesis states that the functionality grid does enhance MOT practitioners' technological literacy.

In order to test the null hypothesis of no difference, the quantitative experiment takes the form of a pretest posttest design held as true design which when correctly employed yields evidence from which causal inferences can be made. The two primary requirements it meets is to have respectively an experimental and a control group to which respondents are randomly assigned, and to have an experimental treatment. Upon the above foundations follows development of the two variables into constructs ready to be applied in the experiment. The functionality grid becomes approximated by a lecture about this theory, and technological literacy becomes approximated by a test developed to measure it as simple percentage score. When completed, these constructs are tested during a pilot exercise and found ready for the main experiment.

Following upon the successful completion of a pilot exercise, the main experiment is formally conducted at the USB, using the WebCT learning tool. This tool helps in significant ways with completion of the whole sequence for this exercise. Among the benefits are random allocation of participants to the experimental group and the control group by the WebCT programme tools, as well as control measures such as allocation of limited access rights for each participant to only his own experimental material and limiting the experimenter effect. From the description and analysis of the results the impact of the functionality grid is discernible across all three levels of the hierarchy of outcomes. More specifically, insofar it concerns the impact upon the top level of this hierarchy, it immediately becomes clear from the higher mean score of the experimental group that the test of technological literacy is difficult to master without an intervention such as the lecture about the functionality grid. In order to test the subsequent assumption of causality between the functionality grid, as independent variable, and technological literacy as dependent variable, more precise analysis follows with a mixed model Repeated Measures ANOVA. This test finally proves causality between the functionality grid and technological literacy. From this follows rejection of the null hypothesis that the functionality grid does not enhance technological literacy, and acceptance of the alternative hypothesis that the functionality grid does indeed enhance technological literacy. More important however, is the wider finding that the functionality grid can be seen to have met the requirements of a paradigm. This test, at the same time, constitutes the first formal statistical test this theory is subjected to, and on this occasion it comfortably escapes disconfirmation.

5.5.2.3 The dual-nature experiment

The functionality grid is now confirmed to make a significant impact across all three levels of the hierarchy of outcomes. With this smaller experiment, this theory is subjected to a final test in order to assess its compliance with the empirical requirements of a paradigm. This test still further subjects the functionality grid to a test of its empirical merits, because of its technical difficulty and dual-nature consisting of quantitative and qualitative method. The results, once again, confirm the research assumptions about the functionality grid, and firmly corroborate the findings of the earlier tests that the functionality grid does make a discernible and significant impact across all three levels of the hierarchy of outcomes.

5.6 THE MAIN CONCLUSIONS

The main conclusion to be drawn for this research is that the functionality grid complies with the requirements of a valid paradigm for MOT. This conclusion is based on the outcomes of both a theoretical and empirical evaluation of this theory.

In terms of the theoretical evaluation it was found that the functionality grid met the ontological, epistemological and theoretical requirements of the paradigm template. The outcomes of these tests indicate that the functionality grid could serve as a foundation for the MOT body of knowledge. Further it was found that the functionality grid served as theoretical exemplar and source of further theoretical innovation in related fields of knowledge.

However, it is clear that the functionality grid has not achieved the status of dominant paradigm, as its diffusion within the profession appears to be limited. At best it can be regarded as an emerging paradigm. Its strength in this role would support the view that the functionality grid could serve as a conceptual anchoring point for the profession.

For the MOT establishment this may be a most startling revelation considering the general lack of coherent structure in the field. Has the field at last attained a focal point to guide it in its future development? And will the single coherent conceptual structure be strong enough to garner the support required to achieve "celebrity status"?

5.7 CRITICAL PERSPECTIVES

The functionality grid succeeds this round of tests. Even if this research systematically met the different theoretical and empirical research objectives set for it as described in Chapter 1, it does not do so without critique. Almost omnipresent is the comment from interviewees and participants in the final experiment that the functionality grid may benefit, and be more practical, by having more dimensions. A specific suggestion in this regard is that time becomes another operand alongside MEI. The addition of dimensions represents, however, an argument well covered by extant research and it may very well be further explored in future, specifically with the kind of dual-nature experiment demonstrated in this instance. From this author's perspective though, the current dimensions of the theory have evolved from very deep ontological foundations. These foundations can rightly be described as imposing, and they have weathered many an intellectual revolution to still survive today, and to still be seen as intellectually productive. So, it would be a mistake to consider additional dimensions to the theory, without due consideration of how their ontological foundations match those already demonstrated for this theory.

Furthermore, there are the comments forthcoming from participants in all three the practical exercises that the functionality grid does not help them understand technology at all, or that frameworks hold to them no appeal. These comments, well measured as they may be, fortunately represent the view of a small minority of participants involved in this study, and so have little effect upon the final results. It does beg the question though of how the theory may be presented to MOT practitioners similarly inclined. Still more, it begs the question as to how as a paradigm the functionality grid may be received by peoples and cultures where formal frameworks originating in classical Western thought have no role to play. As a paradigm for MOT, the functionality grid may meet its nemesis in the form of yet another paradigm from another culture. After all, paradigms are incommensurable and their adherents do not talk to each other.

Linked to the previous point of critique, and from a more general academic perspective, the question can be asked as to how the results of this research can be transferred to the wider academic community. This question follows from the fact that this study, at least insofar it concerns the empirical results, cannot rightfully make a claim towards external validity, and therefore cannot generalise its results outside the confines of the arena in which it was applied. A review of the facts is called for in this instance. The semi-structured interviews were held with a small circle of MOT practitioners who were known to the researcher. They were not randomly selected from a wider and more general sample framework, even if they do represent widely different professions and academic and or business interests. The participants in the pilot exercise for the quantitative experiment were not randomly selected either, but the participants in the quantitative experiment itself volunteered on a random basis. As the 2010 MBA cohort at the USB, they do not, however, represent the wider community of MOT practitioners, or of society in general, and no claim should be entertained in this regard. The same principle applies to the participants in the dual-nature experiment. Even if they randomly volunteered to participate, as members of the 2010 Doctoral Research Training Program, no claim can be made about their representativeness.

The most important reason for the focus on internal validity for this study remains the basic rather than applied nature of the research, and the fundamentally theoretical nature of its inquiry. Upon reflection of the results, it can confidently be stated that the research aim is successfully achieved. The functionality grid is a valid paradigm for MOT in Cape Town inasmuch as it is in Sydney, New York or Cairo, so long as the limitations of this series of tests are clearly spelled out. There is sufficient certainty though, that the results of the theoretical analysis which saw the construction of the paradigm template, and the evaluation of fit of the functionality grid to the paradigm template, will be able to stand its own in the discourse about a theory for MOT. Similarly, there is sufficient confidence in the control measures pursued during operationalisation of the research design, which means replication of these experiments under the same experimental conditions, with an expectation of the same outcome, should be entirely possible.

For now, the functionality grid escapes disconfirmation and it becomes the task of a next test to assess its sustainability as valid paradigm for MOT. Disconfirmation is, however, a powerful vindication of theoretical value. So, with the new found status of emerging paradigm for MOT, the functionality grid holds the promise of more practical yields for the discipline. It is an exemplary solution, and it brings intrinsic conceptual structure to the discipline. The final section therefore examines the contribution of this study to the debate about the theoretical direction in MOT, and it examines future roles for the functionality grid as a paradigm for MOT within the framework of the current discourse in the discipline. In doing so, it also encapsulates the final objective set for this research, viz. to offer recommendations flowing from the results of this study to the MOT community of practitioners.

5.8 RECOMMENDATIONS

5.8.1 Formal recognition

To improve the conceptual strength of MOT it is recommended that the associations and organisations overseeing the profession give explicit recognition to the role of the functionality grid. This can be done by means of presidential remarks when presiding officials give their “state of the profession” addresses.

5.8.2 Professional training

It is recommended that academic and professional development courses employing the functionality grid be widely disseminated within the MOT community. In this respect the overseeing organisations can encourage the development of a master curriculum, based on the functionality grid and techno-analytical frameworks derived from this theory. This could be made available to those MOT programmes seeking to align themselves with the knowledge and skill requirements as formulated by the profession and its standardisation bodies.

5.8.3 Further research

With the functionality grid to serve as a streamlined and coherent conceptual structure for MOT, the following imperatives are to be pursued. They require leadership in technology thought in order to consolidate the debate in MOT upon the firm foundations now created. The following list expands on these priorities:

1. To ensure that the findings in this dissertation have widespread validity, it is recommended that further theoretical and empirical research probe the suggested paradigm status of the functionality grid. Ideally this should be done in different cultural settings. Is there more opportunity for this theory to be tested under different circumstances? It is further

recommended that the implications for the MOT body of knowledge be investigated, and that the implications of the functionality grid as paradigm be taken into consideration in the further formulation of the body of knowledge. Where the functionality grid has yielded a number of techno-analytical frameworks, it is recommended that these frameworks be probed in case studies to ascertain their validity.

2. With conceptual structure and with academic content in place, formalisation and consolidation of courses should follow. Promotion and presentation of the consolidated structure and content would be a final task in order to alleviate the problem of technological literacy.

3. At a more practical level, several problems associated with a lack of technological literacy are ready to be investigated. First on the list from a developing world perspective is an experiment to determine how the functionality grid can serve as a neutral semantic of the particular nature of technology in order to help alleviate the persistent cultural complications disrupting technology transfer. Second on the list is the application of the functionality grid in the creation of a technological, or a taxonomical, frame of reference for decision-making in innovation management. Third, technology intelligence, like knowledge management, remains a much peddled term with successful applications few and far inbetween. As a result, yet another angle is offered by an examination of how the functionality grid can be used to formulate a generic technology intelligence radar screen and to test its implementation and results in the corporate world. Finally, where the functionality grid is used for technological exploration, the question must be answered of how the financial yield of technologies selected with the aid of this framework compare with selections of alternative frameworks.

5.9 CONCLUSION

This study responds in the first place to the debate and divergent viewpoints in MOT circles about the conceptual foundation for this discipline, and its body of knowledge. This problem is made more severe given that MOT is perfectly positioned as an important channel of advance in order to help resolve the omnipresent and economically damaging problem of a lack of technological literacy in society. Following upon this problem statement, this study helps to formalise and streamline the conceptual foundation for MOT by assessing whether the functionality grid complies with the requirements of a paradigm. Pursuing a two-part research strategy, this study consequently shows how the functionality grid complies first with the theoretical requirements of a paradigm, and second with the empirical requirements of a paradigm. Based on the results forthcoming from this study, the functionality grid can be confidently claimed to be a valid paradigm for MOT and to contain the intrinsic capacity to serve as a significant conceptual foundation for the profession. This final chapter presents a review of the research process and of its outcomes, and concludes with critical perspectives and recommendations towards improvement of the status of the functionality grid as paradigm for MOT. The overarching purpose of this study was to contribute to a clearer and more robust conceptual foundation for MOT. With the results and recommendations described here, this study generated a set of conceptual perspectives which should indeed help to bring order and direction to the debate in MOT, and to solve serious and challenging problems in society such as the lack of technological literacy.

REFERENCES

Allchin, D. 2000. Thinking about technology and the technology of “thinking about”. *Techné: Research in Philosophy and Technology,* **5**(1), Fall.

Almirall, E. & Casadesus-Masanell, R. 2010. Open versus closed innovation: A model of discovery and divergence. *Academy of Management Review*, **35**(1), 37–47.

Arthur, W.B. 2009. *The nature of technology: What it is and how it evolves*. New York: Free Press.

Aunger, R. 2010. Types of technology. *Technological Forecasting & Social Change*, **77**, 762–782.

Bacharach, S. B. 1989. Organizational theories: Some criteria for evaluation. *Academy of Management Review*, **14**(4), 496–515.

Badawy, A.M. 2009. Technology management simply defined: A tweet plus two characters. *Journal of Engineering and Technology Management*, **26**(4), 219–224.

Bates, E. 2008. Chimney stoves and smoke hood. *Appropriate Technology*, **35**(2), 50–56.

Bello, D., Leung, K., Radebaugh, L., Tung, R.L. & Van Witteloostuijn, A. 2009. From the editors: Student samples in international business research. *Journal of International Business Studies*, **40**, 361–364.

Belu, D.S. 2005. Thinking technology, thinking nature. *Inquiry*, **48**(6), 572-591.

Belu, D.S. & Feenberg, A. 2010. Heidegger's Aporetic Ontology of Technology. *Inquiry*, **53**(1), 1–19.

Bernard, H.R. 2000. *Social research methods: Qualitative and quantitative approaches*. Thousand Oaks: Sage.

Beukes, P. 1989. *The holistic Smuts: A study in personality.* Cape Town: Human & Rousseau.

Bickman, L. & Rog, D.J. (eds). 2009. *Applied Social Research Methods.* 2nd edition. Los Angeles: Sage.

Biltz, G. 2009. Functional approach to metabolism. Minnesota, USA. Email communication with Dr Rias van Wyk, 2 September.

Bird, A. 2004. *Thomas Kuhn*. Stanford encyclopedia of philosophy. [Online] Available: http://plato.stanford.edu/entries/thomas-kuhn/ Accessed: 7 September 2010.

Bond, P.L. 2006. *Understanding technology as knowledge and culture*. A working paper. [Onlijne] Available: http://www.google.co.za/#hl=en&source=hp&biw=1346&bih=863&q=-Understanding+Technology+as+Knowledge+and+Culture&btnG=Google+Search&aq=f&aqi=&aql=&oq=&fp=e147104b1c77a7a0 Accessed: 14 January 2011.

Bond, P.L. 2003. The biology of technology— An exploratory essay. *Knowledge, Technology & Policy*, **16**(3): 125–142.

Bonet, E., Jensen, H.S. & Sauquet, A. 2009. *Rhetoric in management and in management research.* Working Text delivered at 17th EDAMBA Research Summer Academy, 24–30 July.

Bowonder, B. & Miyake, T. 2000. Technology management: a knowledge ecology perspective. *International Journal of Technology* Management, **19**(7–8), 662–684.

Brabin, L., Roberts, S.A. & Kitchener, H.C. 2007. A semi-qualitative study of attitudes to vaccinating adolescents against human papillomavirus without parental consent. *BMC Public Health*, **7**, 20–27.

Brady, T., Rush, H., Hobday, M., Davies, A., Probert, D. & Banerjee, S. 1997. Tools for technology management: an academic perspective. *Technovation*, **17**(8), 417–426.

Brent, A.C. & Pretorius, M.W. 2008. Sustainable development: A conceptual framework for the technology management field of knowledge and a departure for further research. *South African Journal of Industrial Engineering*, **19**(1), 31–52.

Brewer, J. & Hunter, A. 2006. *Foundations of multi-method research: synthesizing styles.* Thousand Oaks: Sage.

Broens, R.C.J.A.M. & De Vries, M.J. 2003. Classifying technological knowledge for presentation to mechanical engineering designers. *Design Studies*, **24**(5), 457–471.

Bryman, A. & Bell, E. 2007. *Business research methods.* 2nd edition. New York: Oxford University Press.

Burgess, L.A. 2003. WebCT as an e-Learning tool: A study of technology students' perceptions. *Journal of Technology Education*, **15**(1), 6–15.

Cambridge Dictionary of Philosophy. 1999. *Systems theory*. Cambridge: Cambridge University Press.

Cannicea, M.V., Chena, R. & Daniels, J.D. 2003. Managing international technology transfer risk: A case analysis of U.S. high-technology firms in Asia. *Journal of High Technology Management Research*, **14**, 171–187.

Cetindamar, D., Wasti, S.N., Ansal, H. & Beyhan, B. 2009. Does technology management research diverge or converge in developing and developed countries? *Technovation*, **29**, 45–58.

Chanaron, J., Jolly, D. & Soderquist, K. 2002. Technological management: A tentative research agenda. *International Journal of Technology Management*, **23**(6), 618–629.

Christensen, L.B. 1997. *Experimental methodology.* 7th edition. Boston: Allyn & Bacon.

Cockfield, A.J. 2004. *Toward a law and technology theory*. Draft of paper prepared for Canadian Association of Law Teachers Annual Meeting, 2 June.

Cogan, J.M. 2002. Some philosophical thoughts on the nature of technology. *Knowledge, Technology & Policy*, **15**(3), 93–99.

Conant, J. & Haugeland, J. (eds). 2000. The road since structure: Philosophical essays, 1970-1993, with an autobiographical interview. Chicago: University of Chicago Press.

Cryer, J.D. & Miller, R.B. 1994. *Statistics for business: Data analysis and modeling.* 2nd edition. Belmont: Duxbury Press.

D'Costa, A.P. (ed). 2006. *The new economy in development: ICT challenges and opportunities.* Hampshire: Palgrave Macmillan in association with United Nations University and World Institute for Development Economics Research.

DeGregori, T.R. 1985. A theory of technology: Continuity and change in human development. Ames: Iowa State University Press.

Denscombe, M. 2010. *Ground rules for social research.* 2nd edition. Berkshire: Open University Press.

Design Week. 2009. Product design: Community support, **24**(48), 3 December, 16.

Dimitrov, D. & Rumrill Jr., P.D. 2003. Pretest-posttest designs and measurement of change. *Work*, **20**, 159–165.

Doncaster, C.P. & Davey, A.J.H. 2007. Analysis of variance and covariance: How to choose and construct models for the life sciences. Cambridge: Cambridge University Press.

Doppelt, G. 1978. Kuhn's epistemological relativism: An interpretation and defense. *Inquiry*, **21**(1–4), 33-86.

Dosi, G. 1982. Technological paradigms and technological trajectories. *Research Policy*, **11**, 147-162.

Dostal, E. & Cloete, A. 2002. Response to Rias Van Wyk's query on whether a fundamental structure in technology is needed. MINT*/TIM Past E-Mail Transmissions, **9**(49).

Drejer, A. 1997. The discipline of management of technology, based on considerations related to technology. *Technovation*, **17**(5), 253–265.

DST. No date. *Foresight crime report.* [Online] Available: http://www.dst.gov.za/publications-policies/foresight-reports/documents/FORESIGHT%20CRIME%20REPORT.doc/view Accessed: 26 October 2009.

Durbin, P.T. 2006. Philosophy of technology: In search of discourse synthesis. *Techné: Research in Philosophy and Technology,* **10**(2), 1–288.

Fagerberg, J. 2004a. Innovation: A guide to the literature. In Fagerberg, J., Mowery, D.C. & Nelson, R.R. (eds). *Oxford Handbook of Innovation, chapter 1*. Oxford: Oxford University Press.

Fagerberg, J. 2004b. *What do we know about innovation? Lessons from the TEARI project. TEARI project.* Report No. 1, 2nd draft, 20 September.

Farrell, C.J. 1993. A theory of technological progress. *Technological Forecasting & Social Change*, **44**, 161–178.

Fassinger, R.E. 2005. Paradigms, praxis, problems, and promise: Grounded theory in counseling psychology research. *Journal of Counseling Psychology*, **52**(2), 56–166.

Feenberg, A. No date. *Summary remarks on my approach to the philosophical study of technology.* [Online] Available: http://www-rohan.sdsu.edu/faculty/feenberg/method1.html Accessed: 13 August 2009.

Feenberg, A. No date. *Critical theory of technology.* [Online] Available: http://www-rohan.sdsu.edu/faculty/feenberg/CRITSAM2.HTM Accessed: 13 August 2009.

Ferré, F. 1995. Philosophy and technology after twenty years. *Society for Philosophy and Technology*, **1**(1–2), Fall. [Online] Available: http://scholar.lib.vt.edu/ejournals/SPT/v1n1n2/ferre.html Accessed: 13 August 2009.

Feyerabend, P. 1970. Consolations for the specialist. In Lakatos, I. & Musgrave, A. (eds). 1970. *Criticism and the Growth of Knowledge.* Cambridge: Cambridge University Press.

Firestone, W.A. 1990. Accommodation: Towards a paradigm-praxis dialectic. In Guba, E.G. (ed). *The paradigm dialog.* Newbury Park: Sage.

Frank, M. 2005. A systems approach for developing technological literacy. *Journal of Technology Education*, **17**(1), 19–34.

Frankelius, P. 2009. Questioning two myths in innovation literature. *Journal of High Technology Management Research*, **20**, 40–51.

Freeman, C. & Soete, L. 2007. *Developing science, technology and innovation indicators: what we can learn from the past*. UNU-MERIT Working Papers, ISSN 1871-9872, 1–19.

Frigg, R. & Hartmann, S. 2006. *Models in science*. [Online] Available: http://plato.stanford.edu/entries/models-science/ Accessed: 5 December 2010.

Gamire, E. & Pearson, G. (eds). 2006. *Tech tally: Approaches to assessing technological literacy.* Executive summary. National Academies Press.

Georgantzas, N.C. & Madu, C.N. 1990. Cognitive processes in technology management and transfer. *Technological Forecasting & Social Change*, **38**(8), 1–95.

Girden, E.R. 1992. ANOVA repeated measures. *Series: Quantitative applications in the social sciences – A Sage University Paper.* Newbury Park: Sage.

Gjertsen, D. 1989. *Science and philosophy: Past and present*. Harmondsworth: Penguin.

Green, K., Hull, R., McMeekin, A. & Walsh, V. 1999. The construction of the techno-economic: Networks vs. paradigms. *Research Policy*, **28,** 777–792.

Grobbelaar, J.A. 1994. *A theory-based generic approach to the strategic management of technology.* PhD dissertation. Stellenbosch: University of Stellenbosch.

Guba, E.G. 1990. The alternative paradigm dialog. In Guba, E.G. (ed.). *The paradigm dialog.* Newbury Park: Sage.

Handfield, R.B. & Melnyk, S.A. 1998. The scientific theory-building process: A primer using the case of TQM. *Journal of Operations Management*, **16**, 321–339.

Harrison, M.I. 2009. Organizational diagnosis. In Bickman, L. & Rog, D.J. (eds). *Sage Handbook of Applied Social Research*. 2nd edition. Los Angeles: Sage.

Harvey, S. 1980. Objectivity, rationality, incommensurability and more. *British Journal for the Philosophy of Science*, **31**(4), 359–375.

Hayden, M.A. 1991. The development and validation of a test of industrial technological literacy. *Journal of Technology Education*, **3**(1), 1–12.

Hipkin, I. & Bennett, D. 2004. Production competence and knowledge generation for technology transfer: A comparison between UK and South African case studies. Paper delivered at IAMOT 2004.

Hornby, A.S. 1974. *Oxford advanced dictionary of current English*. 3rd edition. London: Oxford University Press.

Howey, R.A. 2002. Understanding software technology. *Knowledge, Technology, & Policy*, **15**(3), 70–81.

Hoyningen-Huene, P. 1993. *Reconstructing scientific revolutions: Thomas S. Kuhn's Philosophy of Science*. Chicago: University of Chicago Press.

Huang, K. 2009. Essential research in technology management. *Journal of Business Research*, **63**, 451–453.

IAMOT 2009. *Accreditation policy and procedure manual for management of technology (MOT).* Graduate Level Academic Program. Coral Gables, Florida: IAMOT Inc.

Ihde, D. 1995. Philosophy of technology, 1975–1995. *Society for Philosophy and Technology*, **1**(1/2). [Online] Available: http://scholar.lib.vt.edu/ejournals/SPT/v1n1n2/ihde.html Accessed: 6 December 2010.

Jain, K. & Narvekar, R. 2004. *Doing MOT research – Putting "Ph" back into research?* Paper delivered at IAMOT, April.

Kautt, M., Walsh, S.T. & Bittner, K. 2007. Global distribution of micro–nano technology and fabrication centers: A portfolio analysis approach. *Technological Forecasting & Social Change*, **74**, 1697–1717.

Kelly, K. 2010. *What technology wants.* New York: Penguin.

Khalil, T.M. & Yanez, M. Jr. 2006. *Building a stakeholder-driven MOT body-of-knowledge framework for educational program evaluation.* Proceedings of the 15th Annual Conference for the International Association for Management of Technology (IAMOT), Beijing, China.

Kirkland, J. 1996 (ed.). *Barriers to international technology transfer.* Dordrecht: Kluwer Academic Publishers.

Kiss, O. 2006. Heuristic, methodology or logic of discovery? Lakatos on patterns of thinking. *Perspectives on Science*, **14**(3), 302–317.

Koh, H. & Magee, C.L. 2008. A functional approach for studying technological progress: Extension to energy technology. *Technological Forecasting & Social Change*, **75**(6), 735–758.

Koh, H. & Magee, C.L. 2006. A functional approach for studying technological progress: Application to information technology. *Technological Forecasting & Social Change*, **73**(9), 1061–1083.

Koslicki, K. 2005. On the substantive nature of disagreements in ontology. *Philosophy and Phenomenological Research*, **LXXI**(1), 85–105.

Kuhn, T.S. 2000a. Afterwords. In Conant, J. & Haugeland, J. (eds). 2000. *The road since structure: Philosophical essays 1970–1993 with an autobiographical interview.* Chicago: University of Chicago Press.

Kuhn, T.S. 2000b. The natural and the human sciences. In Conant, J. & Haugeland, J. (eds). 2000. *The road since structure: Philosophical essays 1970–1993 with an autobiographical interview.* Chicago: University of Chicago Press.

Kuhn, T.S. 1977. *The essential tension: Selected studies in scientific tradition and change*. Chicago: University of Chicago Press.

Kuhn, T.S. 1970a. *The structure of scientific revolutions*. 2nd edition. Chicago: University of Chicago Press.

Kuhn, T.S. 1970b. Logic of discovery or psychology of research? In Lakatos, I. & Musgrave, A. (eds). 1970. *Criticism and the growth of knowledge.* Cambridge: Cambridge University Press.

Kuhn, T.S. 1970c. Reflections on my critics. In Lakatos, I. & Musgrave, A. (eds). 1970. *Criticism and the growth of knowledge.* Cambridge: Cambridge University Press.

Kuhn, T.S. 1962. *The structure of scientific revolutions*. Chicago: University of Chicago Press.

Lakatos, I. 1970. Methodology of scientific research programmes. In Lakatos, I. & Musgrave, A. (eds). 1970. *Criticism and the growth of knowledge.* Cambridge: Cambridge University Press.

Lakatos, I. & Musgrave, A. (eds). 1970. *Criticism and the growth of knowledge.* Cambridge: Cambridge University Press.

Landeweerd, L., Osseweijer, P. & Kinderlerer, J. 2009. Distributing Responsibility in the Debate on Sustainable Biofuels. *Sci Eng Ethics*, **15,** 531-543.

Lechte, J. 2003. *Key contemporary concepts.* UK: Sage. [Online] Available: http://www.credoreference.com/entry/sageukcc/ontology Accessed: 23 September 2010.

Lehman, L.L. 2004. Paradigm development in systematic theology. MTh dissertation. Pretoria: University of South Africa.

Levin, D.Z. & Barnard, H. 2008. Technology management routines that matter to technology managers. *International Journal of Technology Management*, **41**(1/2), 22–37.

Lichtenthaler, E. 2007. Managing technology intelligence processes in situations of radical technological change. *Technological Forecasting & Social Change*, **74**(8), 1109–1136.

Lincoln, Y.S. 1990. The making of a constructivist: A remembrance of transformations past. In Guba, E.G. (ed.). *The paradigm dialog.* Newbury Park: Sage.

Linstone, H.A. (Editor in Chief) 2004. From my perspective: From information age to molecular age. *Technological Forecasting & Social Change*, **71**, 187–196.

Lochner, F.C. 2009. *The functionality model as paradigm foundation for MOT.* Proceedings of the 18th International Conference for the International Association for Management of Technology, Orlando, Florida, 5 April.

Lochner, F.C. 2006. A Cost Maturity Model for Community Informatics Projects in the Developing World. *Journal of Community Informatics*, **2**(2). [Online] Available: http://ci-journal.net/index.php/ciej/article/viewArticle/277/228 Accessed: 29 August 2010.

Lorenz, L.L. & Palm, L.L. 2004. *How manifestation, emotion and intention equate with the theory of technology.* Presentation at MS/MOT, University of Minnesota, CDTL.

Magee, C.L. & De Weck, O.L. 2004. *Complex System Classification*. Paper presented at the 14th Annual International Symposium of the International Council on Systems Engineering (INCOSE), 20–24 June.

Masterman, M. 1970. The Nature of a Paradigm. In Lakatos, I. & Musgrave, A. (eds). 1970. *Criticism and the Growth of Knowledge.* Cambridge: Cambridge University Press.

McAdam, R., Leonard, D., Henderson, J. & Hazlett, S. 2008. A grounded theory research approach to building and testing TQM theory in operations management. *Omega*, **36**: 825–837.

Morganti, M. 2009. Ontological priority, fundamentality and monism. *Dialectica*, **63**(3), 271–288.

Morrison, J.M. 2003. *A contribution to scientific knowledge*. Working paper. Bellville: University of Stellenbosch Business School.

Mortara, L., Thomson, R., Moore, C., Armara, K., Kerr, C., Phaal, R. & Probert, D. 2010. Developing a technology intelligence strategy at Kodak European research: scan & target. *Research Technology Management*, **53**(4), 27–39.

Mouton, J. 2008. *Understanding social sciences research: Concepts, principles and good practices.* University of Stellenbosch Business School Course. Bellville: University of Stellenbosch Business School.

Mouton, J. 2001. *How to succeed in your Master's and Doctoral Studies*. Pretoria: Van Schaik.

Mouton, J. 1987. Thomas, S. Kuhn. In Snyman, J.J. & Du Plessis, P.G.W. (eds). 1987. *Wetenskapsbeelde in die geesteswetenskappe.* Pretoria: Human Sciences Research Council.

Musa, P.F., Mbarika, W.V. & Peso, P. 2005. Calling for programmed technology transfer and adoption strategies for sustainable LDC growth. *Communications of the ACM*, December, **48**(12), 111–116.

NAEP, No date. Technology and Engineering Literacy Framework for the 2014 National Assessment of Educational Progress. Pre-Publication Edition. [Online] Available: http://www.edgateway.net/cs/naepsci/download/lib/249/prepub_naep_tel_framework.pdf?x-r=pcfile_d Accessed: 22 July 2011.

NASA. 2010. Definition of Technology Readiness Levels. [Online] Available: http://esto.nasa.gov/files/TRL_definitions.pdf Accessed: 29 August 2010.

Nicewander, A.W. & Price, J.M. 1978. Dependent variable reliability and the power of significance tests. *Psychological Bulletin*, **85**(2), 405–409.

O'Cathain, A. & Thomas, K.J. 2004. "Any other comments?" Open questions on questionnaires – A bane or a bonus to research? *BMC Medical Research Methodology*, **4**, 25–31.

Oyelaran-Oyeyinka, B. 2010. Africa: Time to go solar. *Appropriate Technology,* **37**(2), 60-62.

Palmberg, C. 2004. The sources of innovations – Looking beyond technological opportunities. *Economic Innovations & New Technology*, **13**(2), 183–197.

Palmberg, C., Pajarinen, M. & Nikulainen, T. 2007. *Transferring science-based technologies to industry – Does nanotechnology make a difference?* Keskusteluaiheita, Discussion Papers, ISSN, 0781–6847, No. 1064.

Peine, A. 2008. Technological paradigms and complex technical systems - The case of smart homes. *Research Policy*, **37**(3), 508–529.

Perez, C. 2002. *Technological revolutions and financial capital: The dynamics of bubbles and golden ages*. Cheltenham: Edward Elgar.

Perez, C. 2001. Technological change and opportunities for development as a moving target. *Cepal Review*, **75**, 109–130.

Petrina, S. & Guo, R. 2007. Developing a large-scale assessment of technological literacy. In Hoepfl, M. & Lindstrom, M. (eds). *Assessment in technology education.* New York: McGraw-Hill

Phaal, R., Farrukh, C.J.P. & Probert, D.R. 2006. Technology management tools: concept, development and application. *Technovation*, **26**, 336–344.

Phaal, R. & Farrukh, C.J.P. 2000. *Technology planning survey – Results.* Cambridge, UK: University of Cambridge, Center for Technology Management.

Podder, N. 1988. Technology and its transfer to less developed economies. In Tisdell, C. & Maitra, P. (eds). 1988. *Technological change, development and the environment: socio-economic perspectives.* London: Routledge.

Pol, E. & Carroll, P. 2004. Reviving and assessing the Kuznets law on innovation. *Economics of Innovation and New Technology*, **13**(2), 127–140.

Remenyi, D., Williams, B., Money, A. & Swartz, E. 1998. Doing research in business and management: An introduction to process and method. Sage: London.

Rencher, A.C. 2002. *Methods of multivariate analysis*. 2nd edition. New York: Wiley Interscience.

Rommel, J. & Christiaens, J. 2006. Beyond the paradigm clashes in public administration. *Administrative Theory & Praxis*, **28**(4), 610–617.

Ropohl, G. 2009a. *Allgemeine technologie: Eine systemtheorie der technik*. Karlsruhe, Universitätsverlag.

Ropohl, G. 2009b. *Allgemeine systemtheorie in der technikforschung*. Email communication, 19 May.

Ropohl, G. 1999a. Philosophy of socio-technical systems. *Techné: Research in Philosophy and Technology*, **4**(3), 59-71. [Online] Available: http://scholar.lib.vt.edu/ejournals/SPT/v4_n3pdf/ROPOHL.PDF Accessed: 25 September 2010.

Ropohl, G. 1997. Knowledge types in technology. *International Journal of Technology and Design Education*, **7**, 65–72.

Ropohl, G. 1979. *Eine systemtheorie der technik.* München: Hanser.

Sagasti, F. 2005. *Intellectual property rights or wrongs? A developing country perspective.* Presented at CropLife International Annual Conference, Brussels, September.

Sagasti, F. 2003. *Knowledge, innovation and international cooperation: The Sisyphus Challenge*. Association of Universities and Colleges of Canada, Ottawa, Canada. [Online] Available: www.aucc.ca/_ppt/sagasti_e.ppt Accessed: 5 December 2010.

Sainio, L. & Puumalainen, K. 2007. Evaluating technology disruptiveness in a strategic corporate context: A case study. *Technological Forecasting & Social Change*, **74**, 1315–1333.

Sarafino, E.P. 2005. *Research methods: Using processes and procedures of science to understand behavior*. New Jersey: Pearson.

Schumpeter, J.A. 1966. *Capitalism, Socialism and Democracy*. 4th edition. London: Unwin.

Schwandt, T.R. 1990. Paths to inquiry in the social disciplines. In Guba, E.G. (ed). *The Paradigm Dialog.* Newbury Park: Sage.

Shaffer, R.J., Jacokes, L.E., Cassily, J.F., Greenspan, S.I., Tuchman, R.F. & Stemmer Jr., P.J. 2004. *Effect of interactive metronome® rhythmicity training on children with ADHD*. IM Research Packet.

Shenhar, A.J., Van Wyk, R.J., Stefanovic, J. & Gaynor, G. 2004. *Technofact: Toward a fundamental entity of technology. A new look at technology and MOT.* Paper delivered at IAMOT, Washington, DC.

Sindre, G., Natvig, L. & Jahre, M. 2009. Experimental validation of the learning effect for a pedagogical game on computer fundamentals. *IEEE Transactions on Education*, **52**(1), 10–18.

Skyttner, L. 2001. *General systems theory, ideas and applications.* Singapore: World Scientific.

Smith, R.D. 2009. *Chief technology officer: Defining responsibilities of the senior technical executive*. Orlando: Modelbenders Press.

Smuts, J.C. 1987. *Holism and evolution*. 2nd edition. Cape Town: N & S Press.

Smuts, J.C. Jr. 1952. *Jan Christian Smuts*. London: Cassell & Company.

Sood, A. & Tellis, G.J. 2005. Technological Evolution and Radical Innovation. *Journal of Marketing*, **69**(3), 152–168.

Tegart, G. 2004. Nanotechnology: the technology for the twenty-first century. *Foresight*, **6**(6), 364–370.

Thatcher, V.S. & McQueen, A. (eds). 1980. *The new Webster encyclopedic dictionary of the English language*. New York: Avenel Books.

Thomas, K. 2009. Adding value to cassava. *Appropriate Technology*, **36**(4), 69–71.

Thomas, M.D. 1985. Regional Economic Development and the Role of Innovation and Technological Change. In Thwaites, A.T. & Oakey, R.P. (eds). *Regional economic impact of technological change.* London: Frances Pinter.

Thompson, C. 2006. *Appropriate technology for East Africa: People driven solutions for online microlending*. A graduation project completed within the design for sustainability group of Delft University of Technology to obtain the MSc degree of Industrial Ecology, Faculty of Applied Sciences, Delft.

Tietze, F., Lorenzen, P. & Herstatt, C. 2007. *The role of the chief technology officer–Responsibilities, skills and qualifications and organizational integration.* Hamburg University of

Technology, Institute for Technology and Innovation Management. [Online] Available: http://www.eitim.org/ Accessed: 13 February 2011.

Van Eijck, M. & Claxton, N.X. 2008. Rethinking the notion of technology in education: Techno-epistemology as a feature Inherent to human praxis. *Science Education*, **93**(2), 218–232.

Van Wyk, R.J. 2011. *Twenty years of management of technology (MOT): A perspective on research*. Paper presented at the 20th International Conference for the International Association for Management of Technology, Miami Beach Resort and Spa, Miami Beach, FL, 12 April.

Van Wyk, R.J. 2010. Technology assessment for portfolio managers. *Technovation*, **30**, 223–228.

Van Wyk, R.J. 2009a. *Technological renewal in the USA: A pivotal role for MOT.* Proceedings: 18th International Conference for the International Association for Management of Technology, Orlando, Florida, April 5–9: Section 16 – Theory of Technology.

Van Wyk, R.J. 2009b. *Text to voice*. Technoscan® Newsbrief, **4**(3), March 31.

Van Wyk, R.J. 2008a. *The future of MOT*. Blog posting on IAMOT forum. [Online] Available: http://iamotforum.ning.com/profiles/blogs/2385809:BlogPost:233?id=2385809%3ABlogPost%3A233&page=1#comments Accessed: 12 February 2011.

Van Wyk, R.J. 2008b. *The functionality grid: A focusing concept for MOT*. 3rd edition. Memo to Circle of Organizational Leaders (COOL), MOT Community.

Van Wyk, R.J. 2008c. Introducing technoscan® newsbriefs. Revised edition. *Technoscan® Newsbrief*, **1**(1), 31 December.

Van Wyk, R.J. 2004a. *A template for graduate programs in management of technology (MOT).* Report to the Education Committee International Association for Management of Technology (IAMOT).

Van Wyk, R.J. 2004b. *Technology: A unifying code*. Cape Town: Stage Media Group.

Van Wyk, R.J. 2003. Report on a credo for MOT. *International Association for Management of Technology.* [Online] Available: http://www.iamot.org/homepage/ACREDOFORMOT-2004.pdf Accessed: 13 August 2009.

Van Wyk, R.J. 2002. Technology: A fundamental structure? *Knowledge, Technology & Policy*, **15**(3), 14–35.

Van Wyk, R.J. 2000. A macro-map of medical technologies: Introductory thoughts. *International Journal of Healthcare Technology and Management*, **2**(1/2/3/4), 204–217.

Van Wyk, R.J. 1984. Panoramic scanning and the technological environment. *Technovation*, **2**(2), 101–120.

Van Wyk, R.J. 1979. Technological change: A macro perspective. *Technological Forecasting & Social Change*, **15**(4), 281–296.

Van Wyk, R.J., Karschnia, B. & Olson, W. 2008. Atlas of technological advance. *Research Technology Management*, **51**(5), 61–66.

Wamae, W. 2006. Creating the capacity to benefit from technological change in developing countries. UNU-MERIT Working Papers ISSN 1871-9872. Maastricht, The Netherlands: United Nations University.

Welman, J.C. & Kruger, S.J. 2001. *Research methodology for the business and administrative science.* 2nd edition. Cape Town: Oxford University Press.

Wikipedia. 2010. *Description for template*. [Online] Available: http://en.wikipedia.org/wiki/Template Accessed: 19 September 2010.

Wonglimpiyarat, J. 2005. The nano-revolution of Schumpeter's Kondratieff cycle. *Technovation*, **25**(11), 1349–1354.

Yanez, M. Jr., Khalil, T.M. & Walsh, S.T. 2010. IAMOT and education: Defining a technology and innovation management (TIM) body-of-knowledge (BoK) for graduate education (TIM BoK). *Technovation*, **30**(7–8), 389–400.

Yanez, M. Jr. & Khalil, T.M. 2007. An accreditation program for MOT graduate education: Recognition of need and a body-of-knowledge framework. *Proceedings: International Association for Management of Technology (IAMOT).*

Zeleny, M. 1979. Cybernetics and general systems – A unitary science? *Kybernetes*, **8**(1), 17–23.

APPENDIX 1

STRUCTURE FOR THE SEMI-STRUCTURED INTERVIEWS

1. Introduction

   Background to research – the functionality grid as a paradigm for MOT.

   Technology and its intrinsic nature

   MOT, Strategic Technology Analysis [STA] and the functionality grid

Introduction by interviewer

2. Introduction to the functionality grid

3. Mindsets – the impact of the functionality grid

4. Tools – towards technology exploration

5. Outcomes, perspectives, reminiscences, futures

Interactive discussion

APPENDIX 2

EMAIL REQUEST TO CONVENER OF FORESIGHT COMMITTEE FOR INTERVIEW

From: Ferdie Lochner
Sent: Monday, February 08, 2010 3:00 PM
To: XXX

F.C. Lochner
Universiteit van Stellenbosch Bestuurskool
Bellville Park Kampus
Charl Cronje Rylaan
Bellville

Gen Maj (afgetree) XXXX

2/08/2010

Beste Generaal

Ek is 'n deeltydse Ph.D.-student by die Bestuurskool van die Universiteit Stellenbosch, waar ek my studie onder leiding van Professor Rias van Wyk voltooi. My navorsingsonderwerp fokus op die nege-sel funksionele klassifikasie-raamwerk en ek toets die intrinsieke kapasiteit van hierdie raamwerk om tegnologiebegrip te bevorder. Op bladsy 58 van die FORESIGHT CRIME PREVENTION, CRIMINAL JUSTICE AND DEFENCE REPORT, waarvan u die sameroeper was, word verwys na die wyse waardeur hierdie klassifikasie-raamwerk benut is om tegnologie vir die doeleindes van bogenoemde verslag te ontleed. Ek wil dus graag 'n navorsingsonderhoud met u voer om uit te vind wat u professionele ervaring van hierdie klassifikasie-raamwerk tydens die samestelling van die verslag was. Sou u my kon tegemoetkom in hierdie verband, of kan u my moontlik na 'n lid van u destydse paneel verwys wat nouer betrokke was by die benutting van hierdie raamwerk? Indien u so gaaf sou wees om my te woord te staan, behoort ek nie meer as hoogstens 45 minute van u tyd in beslag te neem nie.

Ek sien uit daarna om van u te hoor.

By voorbaat dankie.

APPENDIX 3

EMAIL EXCHANGE WITH RETIRED NAVY OFFICER

From: Ferdie Lochner [mailto:Ferdie.Lochner@capetown.gov.za]

Sent: 15 January 2010 01:00 PM

To: XXX

Subject: Request for a formal interview: PhD research about nine cell functional classification framework

F.C. Lochner

University of Stellenbosch
Business School

Bellville Park Campus
Charl Cronje Drive
Bellville

Mr XXX

1/15/2010

I am a part-time PhD student at USB, working under the guidance of Dr Rias van Wyk. My research topic focuses on the nine cell functional classification framework. I am testing its theoretical status by assessing its intrinsic capacity to enhance technological literacy. Dr Van Wyk has referred me to you in order to request the opportunity towards a formal interview about your professional experience with the functional classification framework. If you were to be so kind to grant me the interview, it should at most take up 30 minutes of your time, and can be held at the venue and time of your choice.

I look forward to hear from you.

Sincerely yours

F.C. Lochner

From: XXX

Sent: Tuesday, January 19, 2010 3:35 PM

To: Ferdie Lochner

Subject: RE: Request for a formal interview: PhD research about nine cell functional classification framework

Dear Mr Lochner,

You are welcome to have an interview with me. I fear though that you will not have much satisfaction from it. While I was in the SA Navy our IT requirements were met by INFOPLAN which later became SITA with little or no consultation or input from the users. Although each arm of the Service had its own Director Computer Information Systems (DCIS) he too did not consult the users within his Service. Each arm of the Service was also reasonably autonomous in the way it developed its IT systems with little or no coordination from INFOPLAN. Thus while the SAN developed a very useful intranet system I could not communicate with my Army, SAAF, SAMHS or even DHQ counterparts.

With corporate systems things were not much better except for the PESOL and Finance systems which from the outset were SADF wide. Each Service had its own logistics IT system which could not talk to each other. So as for using Prof Rias' nine cell system, I was too small a cog in too big a wheel to introduce it in a meaningful way.

Now that I have been running my own micro business for the last 8 years it is too small to look seriously at introducing his 9 cell system and one is too busy keeping one's head above water to put time aside for such esoteric exercises, however much I appreciate the value of his classification system. Possibly we are using some of it intuitively rather than in a premeditated fashion.

If after that short explanation you would still like to have an interview with me you are welcome to do so.

Yours aye,

XXX
(R ADM(JG) A.A. XXX
CHIEF OPERATING OFFICER: XXX

From: Ferdie Lochner

Sent: Wednesday, January 20, 2010 3:11 PM

To: XXX

Subject: RE: Request for a formal interview: PhD research about nine cell functional classification framework

Dear Mr XXX

It is with the sincerest appreciation that I receive your response. I would certainly like to meet with you for a formal interview, even if you already have been so kind to share your general impressions about management of Information and Communication technologies in the SANDF. My study focuses on the wider conception of technology across the spectrum, whether indeed a system like a computer or a platform with countless systems, like a submarine. I would accordingly like our discussion to focus on aspects such as your naval technology reconnaissance work, if you'd be so kind.

Although I am based in Durbanville Civic Centre, I visit the Civic centre regularly for work purposes. So we are in close proximity and I will contact you within the next two weeks for a formal appointment.

Sincerely yours
Ferdie Lochner

APPENDIX 4

EMAIL EXCHANGE WITH TELECOMS EXECUTIVE

Dear Ms XXX

Please accept my sincerest appreciation as well for your willingness to grant me a formal interview about your professional perspectives upon the functionality grid. I am not sure whether you are located in Cape Town or Johannesburg? Would you be so kind to let me know, so that I may propose a number of alternative dates for a meeting of approximately one hour. Your preferences in this regard are also more than welcome.

I look forward to hear from you.

Dear Ferdie

I am Cape Town based in our Century City offices. XXX can you liaise with Ferdie to arrange a meeting for us in the next few weeks.

Hi Ferdie,

My sincere apologies for not responding as yet – XXX was planning on travelling but it's all changed again. I wanted to be absolutely sure about her movements before confirming the interview date.

She is only available on Fri, 19th and the then the following week – please advise which morning will suite you best?

APPENDIX 5

EMAIL REQUEST FOR EXCHANGE WITH LECTURER AT THE UNIVERSITY OF MINNESOTA

Dear Dr XXX

My PhD supervisor, Dr. Rias van Wyk, referred me to you in connection > with the application of the functionality grid in your physiology classes. From my provisional research findings this is an atypical application of the model in the sense that it is mostly applied by Management of Technology [MOT] practitioners towards technology exploration. Would you mind sharing with me a few thoughts on how it came that you resolved to use this model for this purpose? If indeed, please consider to respond to the following questions:

1. How in your mind did the functionality grid come to present to you the attributes of 1)an intellectually useful and 2) a practically employable model?

2. If you'd allow me to ask, did the discipline of physiology not have useful models to apply in this role? Why not General Systems Theory itself, for example?

3. From your liaison with Dr. Van Wyk I gather that you foresee more use of the functionality grid in your classes. Also, I understand that he sent you my earlier IAMOT submission about the Functionality model as paradigm for the discipline of MOT. Given the above, and not assuming that you had the opportunity to read my paper, how do you foresee the future role of this model in 1) your profession and 2) in other disciplines such as MOT? Does it have theoretical merits at all?

I thank you for your kind consideration of the above.

APPENDIX 6

SEMI-STRUCTURED INTERVIEWS – DATA

INTERVIEWEE 1

1. Introduction
   i) Background to research – the functionality grid as a paradigm for MOT.
   ii) Technology and its intrinsic nature
   iii) MOT, Strategic Technology Analysis [STA] and the functionality grid

Introduction by interviewer

2. Introduction to the functionality grid

Interviewee has an electronic engineering degree and a MBA. He got introduced to STA by reading Van Wyk's book titled *Technology: A Unifying Code.* At first did he did not think it offered any substance, other than yet another conceptual framework for thinking about technology and MOT.

3. Mindsets – the impact of the functionality grid

The nine cell matrix of the functionality grid left however an impression upon his mindset, and after 2 weeks the interviewee read the book again. Light went up when at closer inspection he found that the grid could be used to connect dots about future developments in technology, and to bring clarity to the vagueness on the technological horizon. The grid, therefore, had an intellectual impact by the imprint it left. He did now think that the grid offered a framework for technology thought.

4. Tools – towards technology exploration

The interviewee teaches ICT at the USB, and writes for the USB Institute of Futures Research [IFS] on technology futures. He uses the functionality grid as an overarching framework for thinking about technologies in his MBA classes. He follows conventional practice and classifies technology in categories such as transport, medical, nano and information technologies. Uses then the grid to offer a holistic view upon the meta trends in technological development. He does not use the grid though in his private consultations, which are mainly in the ICT industry.

5. Outcomes, perspectives, reminiscences, futures

The interviewee foresees that the functionality grid will be used more in his own writings for the IFS, and he currently considers ways and means of extending its use. He fully agrees that the grid offers the possibility of becoming a paradigm for thought about technology and MOT. He thinks too that the grid will in the true paradigm sense offer the possibility to be tested as a theory and will help to present answers to industry questions about technological development and management thereof. He is critical though about the two dimensions and the three classes on each axis. He feels there should be more exploration of the multi-dimensional potential of the grid, proposing time as an additional operand to MEI. The <u>interviewer</u> does refer here to the distinction by Van Wyk between symmetric use versus assymetric use of the functionality grid. Symmetric in its pure 9 cell form, against assymetric in the forms proposed by Magee & De Weck of MIT. The interviewee asks whether more dimensions would not pose more business value. He also feels the circle of adherents should elicit critique about the grid so as to help it evolve in theoretical status. These comments follow upon the interviewer's comment about the task of the scientist to be critical and cynical in order to subject the construct of interest to as many as possible tests.

Interactive discussion

INTERVIEWEE 2

1. Introduction
   i) Background to research – the functionality grid as a paradigm for MOT.
   ii) Technology and its intrinsic nature
   iii) MOT, Strategic Technology Analysis [STA] and the functionality grid

Introduction by interviewer

2. Introduction to the functionality grid

Interviewee has a degree in Military Science a MBA. He got introduced to STA via a MOT course forming part of his MBA.

3. Mindsets – the impact of the functionality grid

The interviewee immediately felt that the functionality grid offered a pathway to understanding of the basic technological trends. The interviewee reports that the functionality grid unlocked to him an outcomes-based understanding of technology. It had a "formative" impact as part of the academic development process he endeavored on for the MBA. And rightly so he feels, because he had the inquisitiveness of a student and wanted to learn more.

4. Tools – towards technology exploration

After his introduction to the functionality grid the interviewee used the grid "extensively" for understanding of complex technologies in a course he did as navy officer at the South African weapons manufacturer ARMSCOR during 1997. He also wanted to use the grid in as an aid to navy officers for framing technologies in a Total Quality Management [TQM] approach the navy adopted during 1998. This effort however was not successful, and he never got so far to employ the functionality grid in this role. Discussing TQM, both parties agree that there is in fact a relationship between TQM, the philosophy of holism and STA.

5. Outcomes, perspectives, reminiscences, futures

The interviewee has retired from the navy and now runs a marine training academy. Post-retirement he did apply his mind again about the functionality grid. It was a toolset useful at a certain stage of his career, and he did not think it useful in his new role "I have moved on". The grid is not required in order "to survive and thrive". The grid did leave though a residual in his mind about technology understanding. He does furthermore maintain that the grid plays a key role in technology understanding, based on his own experience. The grid still has a role to play in describing technology outcomes and it certainly holds much value to MOT practitioners. He agrees that the grid may evolve into a generally agreed upon practice. He is also critical about the symmetric use and feels that more dimensions added may hold more business value.

Interactive discussion

INTERVIEWEE 3

1. Introduction
   - i) Background to research – the functionality grid as a paradigm for MOT.
   - ii) Technology and its intrinsic nature
   - iii) MOT, Strategic Technology Analysis [STA] and the functionality grid

Introduction by interviewer

2. Introduction to the functionality grid

Interviewee has is a post-graduate in Microbiology and a MBA. She got introduced to STA via the Institute for Futures Studies through which Van Wyk presented a one day workshop at her company.

3. Mindsets – the impact of the functionality grid

The interviewee feels that the functionality grid had grown to specific employable construct in her mind. But it did not happen easily, and it required additional work and study to understand its use and its value. She feels a single exposure to the functionality grid would not have an impact upon the individual executive. She does think that the grid has a definitive role to fulfill in promoting technological literacy.

4. Tools – towards technology exploration

After the introduction to the functionality grid, the interviewee used the grid to structure the technology section of a strategic initiative launched by her company. This did however not happen intuitively, since the champion for deployment of the construct resigned, and she had to take up the baton.

5. Outcomes, perspectives, reminiscences, futures

The interviewee feels the grid fulfilled a key role in structuring technology thought in her company. She plans to roll out its use as construct for analysis and synthesis of technology strategy and MOT in a much more "aggressive" manner in the future. Her subordinates have also had exposure to the grid. She feels the grid must in fact play a "central role" in the task of setting technology scenarios. Using the grid in a meaningful role requires however a dedicated champion.

Interactive discussion

INTERVIEWEE 4

1. Introduction
   - i) Background to research – the functionality grid as a paradigm for MOT.
   - ii) Technology and its intrinsic nature
   - iii) MOT, Strategic Technology Analysis [STA] and the functionality grid

Introduction by interviewer

2. Introduction to the functionality grid

The interviewee has a degree in Economics and a MBA. He got introduced to STA via a presentation Van Wyk made at a Leaders' Angle leadership event at the USB. The Leaders' Angle event is a monthly leadership talk arranged by a USB alumni association.

3. Mindsets – the impact of the functionality grid

The interviewee realized there was not a uniform and manner to describe technology. The interviewee is in the recycling business and pursues a PhD on the topic of "liveability versus sustainability". He holds strong thoughts about society's tendency to "not think about technology…it is not my problem…it is someone else's problem….we bury our assumptions about technology". The functionality grid brought along a very strong new conception of technology to this interviewee. It is nothing else than a mindset change about the overall picture or conception he has about technology.

4. Tools – towards technology exploration

After the introduction to the functionality grid, the interviewee immediately started to use the grid in his submissions about recycling technology proposals. An extract of one of these submissions showing how he uses the grid is appended hereto as an example. The interviewee

5. Outcomes, perspectives, reminiscences, futures

The interviewee spent three years exploring the most appropriate technology options for conversion of discarded tires into useful by products. He is now of the opinion that the investigation could have been completed much sooner had he been familiar with the construct of the functionality grid and the power it offers towards technology exploration. The interviewee describes the grid as a framework or a "common language" with which professionals with different points of view can talk to each other about technology. The grid is therefore to him a neutral language without the "complexities and difficulties of Mathematics and Physics".

Interactive discussion

APPENDIX 7

EMAIL RESPONSE FROM LECTURER AT THE UNIVERSITY OF MINNESOTA

Greetings Ferdie,

Thank you for your inquiry about how I use the functionality matrix in the context of physiology. I will be able to give you more complete answers to your questions this weekend. I am preparing for a Thursday presentation on the urinary system to 3M Infection Prevention group. The lecture series is titled: Functional Physiology at Work (FPW). Last year at 3M I did previous FPW modules on the Cardio-Respiratory system and Skin Defenses that included immunology. I have adapted the MOT Functionality matrix into a Biodynamics matrix. I will attach examples in the next e-mail.

When Rias first shared the MOT Functionality matrix, it was obvious that the functionality framework fit biological systems. Biological systems are instantiations of matter,energy and information (MEI). In fact, a biological molecule like ATP can function as all 3 "features". This nicely illustrates the interchangeability of MEI as 3"things".

Transport, Process and Store are also fundamental to biological system whether whole organisms or singular cells. Thus, the 9 cell matrix very nicely "maps" the fundamental functions found in all biological systems.

James Miller developed a much larger biological matrix model in the 1970's but it was too large and too complete to be versatile. The 9 cell matrix is sufficient, adaptible and therefore a useful conceptual tool.

I have adapted the biodynamics matrix by placing the transport column first. The fundamentals of cell biology and physiology start with membranes and the movement of molecules across or through them. In fact, "flow" is the operative construct in physiology. Everything flows - water, air, blood, oxygen, sodium, calcium, hydrogen, ATP, etc.

I have annotated the matrix to reflect physiologic features. The same matix framework holds across levels of description from whole organism to cellular level. So, one has a consistent way to map and discuss physiological phenomenon at any level of description. The goal is not about putting features into one categorical box or another. The goal is to parse a physiologic phenomenon into its component features, keep track of the relationships and keep the inquiry in focus.

The matrix becomes a tool for problem representation and hypothesis generation. The matrix becomes a way to think about phenomenon in a dynamic or functional schema. This is a different from the classic descriptive outlines found in textbooks. Classic descriptive outlines do not capture dynamical or operative relationships. The Functionality matrix does. Have I made any sense?

I will more formally answer your questions in the next e-mail.

Best Regards,

APPENDIX 8
THE FUNCTIONALITY GRID LECTURE

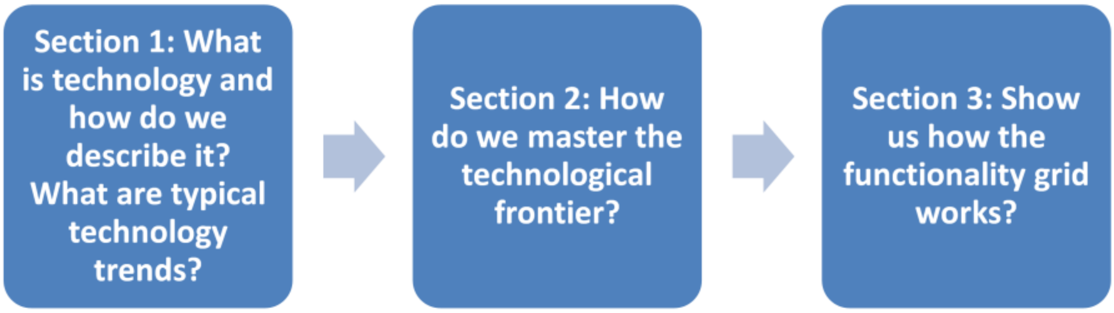
Using the Functionality Grid to Enhance Technological Literacy

Presented by: Ferdie Lochner
Date: 20 May 2010

Colleagues and friends

We are all to a more or lesser extent aware that new technologies abound, whether we are introduced to these technologies as private citizens, or whether we have to make decisions about these technologies in our professional capacity. From within the discipline of Management of Technology, our consistent observation is that we most often do not understand these technologies to the extent where we would confidently be able to make decisions about them. Given this, my PhD research focuses upon an analytical framework known as the functionality grid. This framework is meant to help technology decision-makers, that is typically all of us, to understand the basic essence of each technology we read about in subject papers, journals, advertisements, sales pitches and elsewhere, and to understand it production outcomes. My request to you is therefore to listen to this presentation and to learn how this grid helps us to become technologically literate. Thank you once again for your willingness to participate!

The roadway towards technological literacy



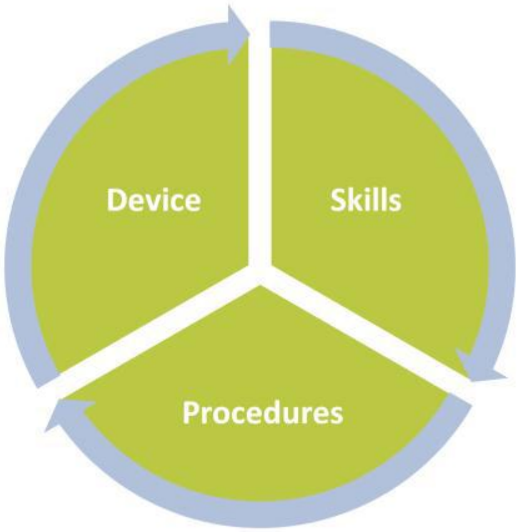
This presentation starts with an introduction to the notion of technology by way of a practical definition. Introducing some examples of new technologies, it then deals with some of the trends we observe in technology change.

In a second section, I present to you a simple sequence of how we may better understand these changes, and the technologies that are the results of these trends. Specifically, the road towards mastery of technological literacy runs through the functionality grid, and that's why when we reach this point I will introduce to you this framework and its practical nature.

In a final section, I am to demonstrate to you how the functionality grid works with four examples; and this should help you with the subsequent short evaluation, because the evaluation is based on precisely the same logic as these case studies.

The request to you is to use this slidecast to gain insights into the nature and practical working of the functionality grid. Remember: the intent is to help you understand this framework, so that you are able to apply it in a practical test which follows when you have concluded your learning session. In this regard, I'd like to remind you to kindly complete the test within 24 hours after having studied these contents.

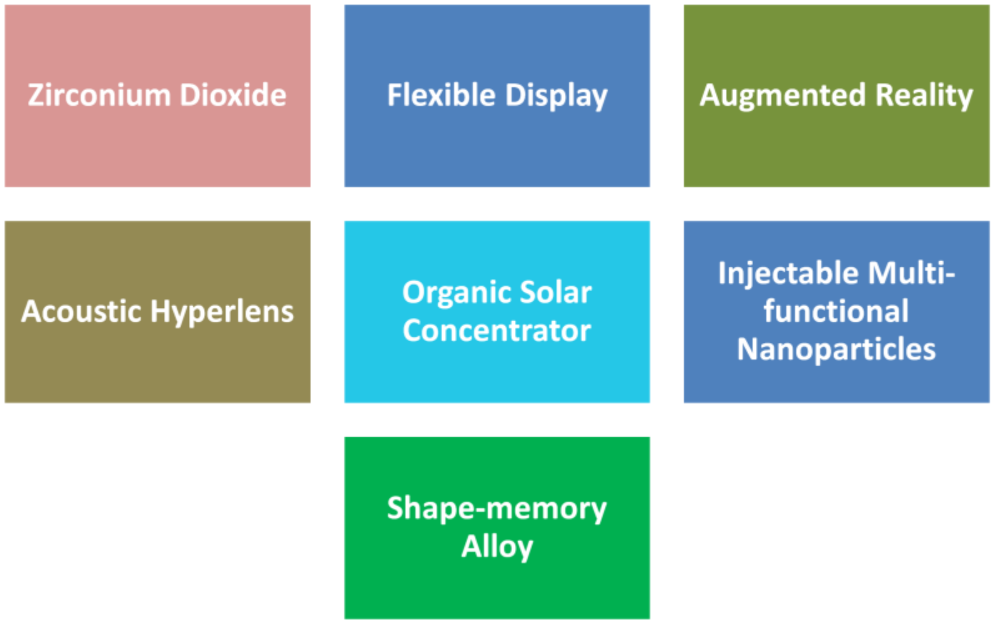
How do we describe technology?



Source: Based on a description by Van Wyk, R.J. 2009a.

Like with all academic concepts, the notion of technology too is known for its countless definitions. For our purposes, we will settle on a practical view recommended by an expert in this field, i.e. Dr Rias Van Wyk. In accordance with this view, technology consists of a set of skills, a set of procedures and a device. The interaction between these three elements applies across the life cycle of a specific technology, from initial conceptualization through design, prototyping, manufacturing, gainful use to retirement. When you read about new technologies, even should they appear at first sight as nonsensical to the untrained eye, do remember that these technologies consists of these elements, and that when we proceed to analyze these technologies, we will see how the combination of these elements makes for productive outcomes generated by each technology.

Technology trends and manifestations

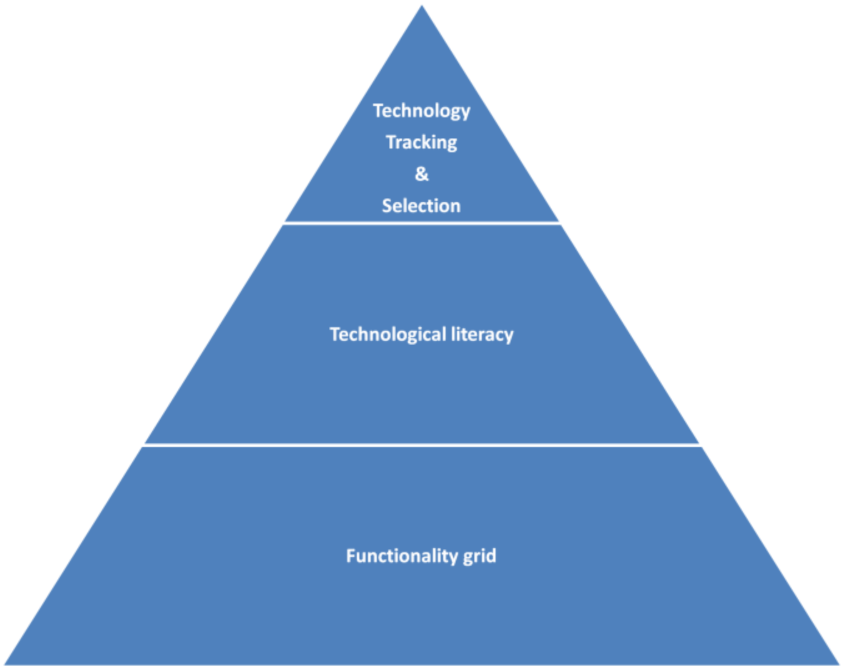


We are introduced here to a number of technologies which have attracted the attention of technology observers. As a collection of innovative new ideas, they represent the following trends:

- Increasing complexity.
- Increasing range of size from micro to macro.
- New principles of operation.
- Use of new materials.
- Increasing performance, efficiency and accuracy.

These technologies are the result of a combination of forces, consisting among others of research and development, science, innovation and consumer demand. One is left with a deep impression of the diversity and omnipresence of new technologies. Whether they are only concepts, or have gone to market, some of these technologies may be immature and most will in fact not be well understood at all. Yet they are among the new generation of technologies which will help to achieve better operational and environmental outcomes, and will lead their proprietors to make money.

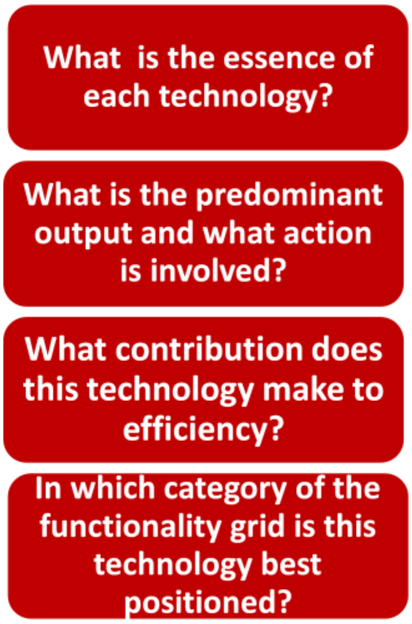
Mastering the Technological Frontier



Having been introduced to these new technologies and associated technology trends, our task as technology decision-makers is to track these technologies and to select from among them those that make most sense to our stakeholders, by which I mean our businesses, our shareholders, our societies and our environment.

But to be able to do technology tracking and selection, we must first use the functionality grid to become technologically literate. With insights attained via the grid, technological literacy helps our mindsets via technology tracking and selection to form an aggregate or holistic overview about potential pathways for the technologies we focus on, so that when we think of these technologies we are able to anticipate ahead through the many and confusing signals we receive about future developments and the value they may bring. The sequence is therefore one of using the functionality grid to become technologically literate, so that through technology tracking and selection we are able to focus on the most promising technologies which will yield the best opportunities for harvesting their benefits.

The functionality grid questions



What are these technologies we have just seen? Why would we consider to invest in any one of these technologies? The following questions are therefore questions one asks as part of the technology tracking and selection process. These are the questions embodied in the logic of the functionality grid itself, and they are as follows:

- What is the essence of each of these technologies? What makes it an innovation?
- What is the predominant output and what action is involved? In other words, what is the functional role this technology fulfills?
- What contribution does this technology make to efficiency?
- Amidst so many technologies, how would each technology be classified in terms of its functional outcomes?

These are the questions posed by a technologically literate mindset. And the purpose of this presentation is, to remind you, to show how the functionality grid enhances technological literacy so that we are indeed able to ask and answer these questions about each technology we observe and analyze.

Roots in Germanic philosophy

Funktionsklasse		Handlung	Transport	Speicherung
Output		Produktiontechnik	Transporttechnik	Speicherungtechnik
Materie	Materietechnik			
Energie	Energietechnik			
Information	Informationtechnik			

Source: Ropohl, G. 1979.

But if we say we should use the functionality grid to become technologically literate, what is the functionality grid and where does it come from? Why does it appear to be the most appropriate to help us understand technology outcomes among several economic and technological classification schemes?

In its original form, the functionality grid is a nine cell matrix which juxtaposes functional outputs to ways of handling. The father of this framework is German philosopher Gunther Ropohl. Originating in the German school of philosophy, the argument for functional analysis of technology by Ropohl is a response to the need for better understanding of technology by philosophers, economists, industrialists and society at large.

From its appearance, we can see it contains the logic of systems thought, i.e. input – action – output. At the same time, it also appears holistic. Matter, energy and information represent the total physical reality, whereas process, transport and store as types of action provide for the deconstruction of all industrial operations, from the simplest to the most complex.

The functionality grid for a macro-perspective

		Action		
		Process	**Transport**	**Store**
Output	**Matter (M)**	Transforming substances	Moving substances	Holding substances
	Energy (E)	Generating energy	Transmitting energy	Keeping energy
	Information (I)	Composing information	Sending information	Saving information

Source: Van Wyk, R.J. 2010a.

Since its introduction in 1979, Dr Rias Van Wyk refined Ropohl's original nine cell matrix into the functionality grid as it is to appear here. Van Wyk proceeded to pioneer its use in strategic technology analysis and various associated applications.

The grid classifies each technology in terms of its predominant output. This helps us to understand at once with *what* physical reality a specific technology deals, i.e. matter, energy or information.

It also helps us to identify immediately *how* the technology under review deals with this physical reality, i.e. whether it processes, transports or stores it.

As a combination, the interaction between these two axes produces the nine pathways of transforming and classifying physical reality. Dr Van Wyk refers to these cells as the nine pathways towards technological perfection. So, we see spontaneously how the new technology's way of handling contributes to higher efficiency. That is to say, by classifying the device under observation, the grid shows us how the new technology represents technology progress by doing more with less, doing it quicker and/or taking up less space to do so.

Case Study 1: A new voice processing technology

		Action		
		Process	Transport	Store
Output	Matter (M)	Transforming substances	Moving substances	Holding substances
	Energy (E)	Generating energy	Transmitting energy	Keeping energy
	Information (I)	Composing information	Sending information	Saving information

Source: Van Wyk, R.J. 2009b.

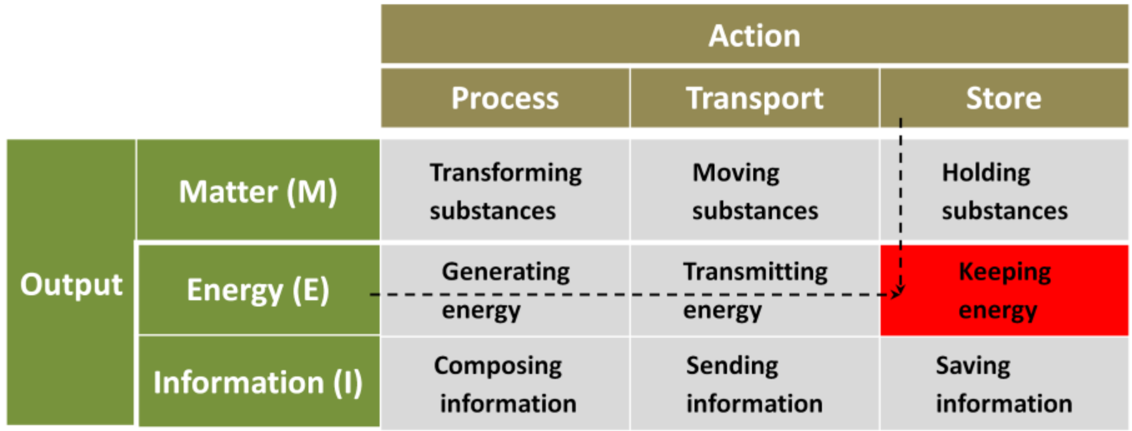
Technoscan® Newsbrief constitutes of a free monthly newsletter to subscribers, and every edition introduces a new technology and positions it in the most appropriate category, or cell if you like, in the functionality grid.

The following four examples serve as typical case studies of how this publication uses the functionality grid to explain the basic attributes of technologies under review.

The first table to be shown here involves a new voice processing technology that transmits written text to electronic voice, demonstrating the functionality of information transmission where the output is information and the way of handling is transportation. In this instance, the new technology is associated with greater clarity, versatility and accuracy of processed voice content.

Following the logic presented by the functionality grid, we see how 1) the basic essence of this technology is described, i.e. a new voice processing technology; 2) how its main output is described, i.e. this technology acts upon information to transport it; 3) how it contributes to higher efficiency, i.e. greater clarity, versatility and accuracy of processed voice content in comparison to existing voice processing technologies; and 4) how it finally is positioned in the functionality grid, i.e. in the category, or the cell, for sending information. This and the next three example demonstrate to us how the functionality grid helps us to understand technology in terms of its functional outcomes, by positioning, or classifying, the technology under review in the category that best describes these functional outcomes.

Case Study 2: The magnetization of polymers



Source: Van Wyk, R.J. 2009c.

Our second example demonstrates a new technology described as the magnetization of polymer materials, involving the functionality of energy storage where the output is energy and the way of handling is storage. Although still in the laboratory, polymer magnets represent advances in stability, strength and tunability, which means an entirely new series of novel magnet products may follow.

1) The basic essence of this technology is the magnetization of polymers; 2) this technology acts upon energy to store it; 3) its contribution to higher efficiency manifests via increases in stability, strength and tunability in comparison to existing energy storage mediums; and 4) it is positioned in the functionality grid in the category for keeping energy.

Case Study 3: A new source of blue pigmentation

		Action		
		Process	Transport	Store
Output	Matter (M)	Transforming substances	Moving substances	Holding substances
	Energy (E)	Generating energy	Transmitting energy	Keeping energy
	Information (I)	Composing information	Sending information	Saving information

Source: Van Wyk, R.J. 2009d.

Our third example demonstrates a technology described as a new source of blue pigmentation, involving the functionality of matter processing, where the output is matter and the way of handling is processing. The production of blue pigmentation holds several challenges for industry, because of high costs, toxic nature, and quality problems. Researchers at Oregon State University have found a source of blue pigmentation consisting of a combination of three materials, i.e. manganese oxide, yttrium oxide and indium oxide, which promises to be more affordable, non-toxic and of a non-fading quality.

1) The basic essence of this technology is the production of blue pigmentation; 2) this technology acts upon matter to process it; 3) its contribution to higher efficiency manifests via increases in quality, and its non-toxic nature; and 4) it is positioned in the functionality grid in the category for transforming substances.

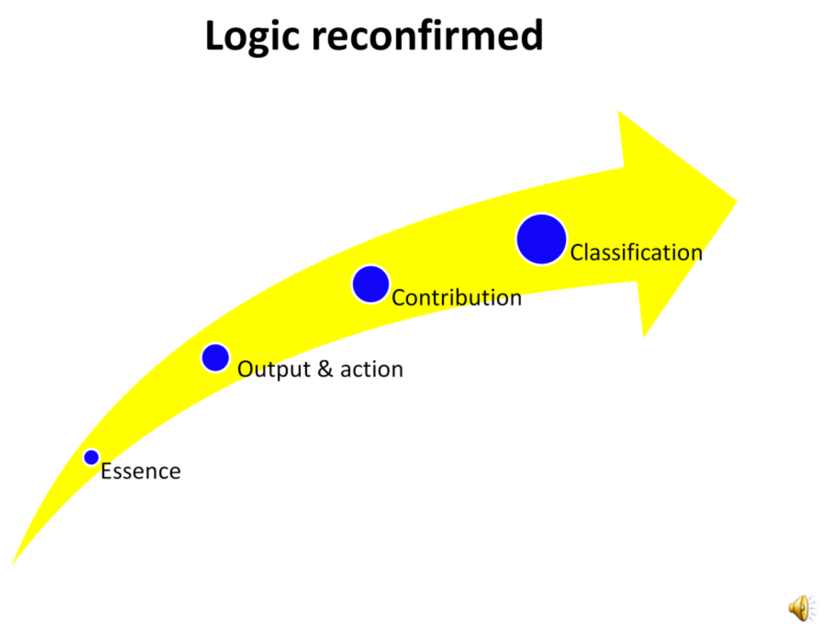
Case Study 4: The levitation of living organisms

		Action		
		Process	Transport	Store
Output	Matter (M)	Transforming substances	Moving substances	Holding substances
	Energy (E)	Generating energy	Transmitting energy	Keeping energy
	Information (I)	Composing information	Sending information	Saving information

Source: Van Wyk, R.J. 2009e.

Our final example demonstrates a new technology described as the levitation of living organisms, involving the functionality of matter transportation, where the output is matter and the way of handling is transportation. While still in a very early stage of development, levitation of fluids and living organisms may yield novel industrial applications, with specific reference to transportation of matter.

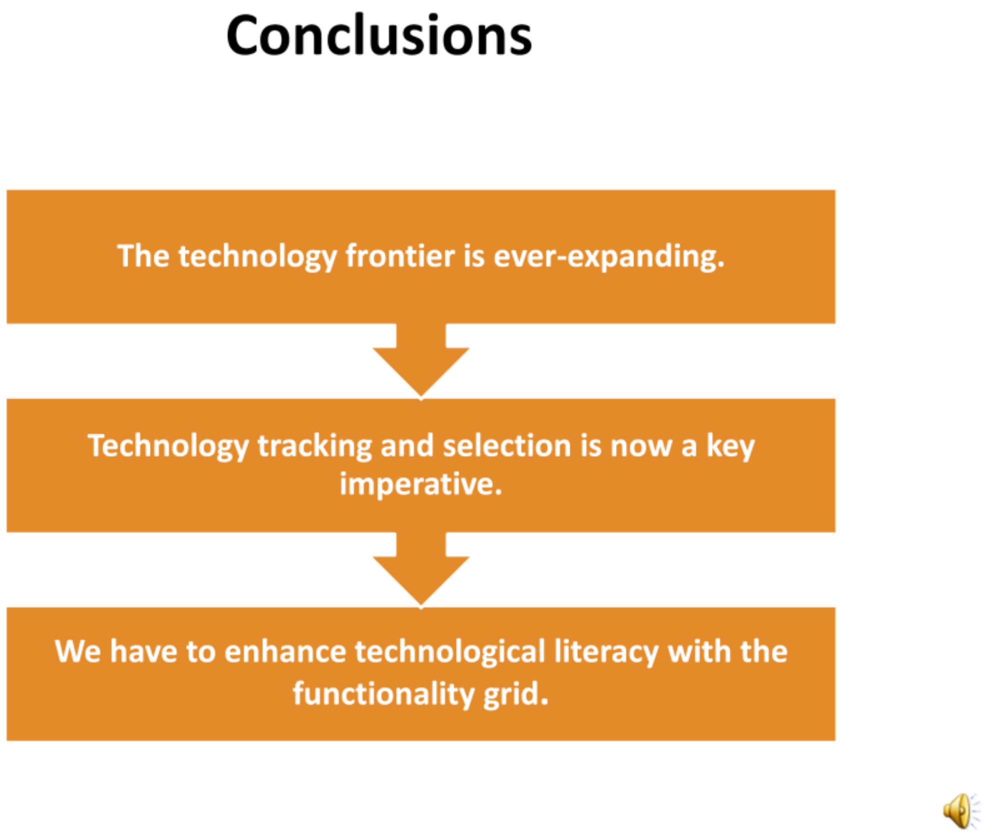
1) The basic essence of this technology is the levitation of living organisms; 2) this technology acts upon matter to transport it; 3) its contribution to higher efficiency manifests in the possibility of novel means of transportation; and 4) it is positioned in the functionality grid in the category for moving substances.



We have now seen four examples of how the functionality grid works with technologies reviewed in the *Technoscan® Newsbrief*. These technologies are real and each one of them finds itself at a particular technology readiness level, whether concept, prototype or completed system tested and demonstrated in an operational environment. The structure of analysis, the sequence of questions and the type of answers we saw are all the same as is to follow in the final test we are to complete subsequent to this presentation. Let's therefore have a final demonstration of how the functionality grid works with a fictional technology described only as a tyre safety responder:

1. What is the essence of the technology under review? The essence of this technology is to help drivers to control their vehicles under emergency situations.
2. What is the pre output and what action is involved? This technology acts upon information to transport it.
3. What is this technology's contribution to efficiency? This technology presents a fail proof intervention to fleet owners for helping their drivers to keep vehicles on the road when they experience unexpected flat tyres or blow-outs.
4. How is this technology positioned in the functionality grid? This technology is positioned in the functionality grid in the category, or the cell, for sending information.

At the end of this sequence, we have gained a panoramic overview of the basic tenets presented by the technology we seek to analyze. We know now what it is, what it does, what its innovation contribution is and how to position it in the functionality grid. This promotes technological literacy and enhances our ability to practice technology tracking and selection.



The technology frontier is ever-expanding. To help us understand and pursue the commercial imperatives of novel technology-based innovations, technology tracking and selection becomes a key imperative. But it requires technological literacy. To help us towards this, the functionality grid presents a simple and standardized protocol for understanding, describing and classifying technology outcomes. To the technically minded among us it presents many leads to follow towards more complexity. To busy executives among us, simple, logical and easy to illustrate answers such as those forthcoming from the functionality grid will help to direct our attention to the most deserving technology opportunities.

Having an overview of the basic tenets of each of these technologies, we can then resolve a course of action to pursue the benefits of each.

To conclude, the functionality grid presents a one page overview of the nine pathways of technology perfection. Its nature and appearance are concise, its logic is coherent and its reach is comprehensive.

I thank you and wish you an exciting experience with your test!

References

- Ropohl, G. 1979. Eine Systemtheorie der Technik. Hanser: München.
- Van Wyk, R.J. 2009a. Technological Renewal in the USA: A Pivotal Role for MOT. *Proceedings: 18th International Conference for the International Association for Management of Technology, Orlando, Florida, April 5-9, 2009: Section 16 – Theory of Technology.*
- Van Wyk, R.J. 2009b. Text to Voice. *Technoscan® Newsbrief*, Vol. 4, No. 3, March 31.
- Van Wyk, R.J. 2009c. Polymer magnets. *Technoscan® Newsbrief*, Vol. 4, No.10, October 31.
- Van Wyk, R.J. 2009d. A new blue. *Technoscan® Newsbrief*, Vol. 4, No. 11, November 30.
- Van Wyk, R.J. 2009e. Levitating living organisms. *Technoscan® Newsbrief*, Vol. 4, No.12, December 31.
- Van Wyk, R.J. 2010. Technology assessment for portfolio managers. *Technovation*, 30: 223 - 228.

APPENDIX 9

THE PRETEST OF TECHNOLOGICAL LITERACY

Test

1. Technology:

Organic Solar Concentrator

Description:

The Organic Solar Concentrator prevents sunlight from being wasted by guiding light photons to solar cells at the edges of organic-dye-tinted plates, improving the intrinsically expensive mechanics of conventional sunlight collection and increasing the efficiency of existing solar panels by up to 50 percent.

Test questions to be answered:

Question 1: What is the essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

2. Technology:

High efficiency lithium-ion cells

Description:

Whereas the the current generation lithium-ion batteries can only sustain a few hundred charge-and-discharge cycles, the next generation lithium-ion batteries can sustain 1000 cycles without loss of cell capacity over time. Given the potential this holds towards more efficient battery life management for the portable electronics industry, Hewlett Packard concluded a deal with innovator Christina Lampe-Onnerud's Boston Power.

Test questions to be answered:

Question 1: What is the essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

3. Technology:

Flexible Display

Description:

Polymer Vision's *Readius* is the first mobile device with a screen bigger than the device itself. The device uses a paper-thin rollable display incorporating electronic ink to display information. This small electronic device is easily carried and stored, but it presents the functionality and user-friendliness of a large electronic display.

Test questions to be answered:

Question 1: What is the essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

4. Technology:

Direct carbon fuel cell

Description:

A new generation of "direct carbon" fuel cells avoids hard to produce hydrogen by sourcing their energy from an electrochemical reaction between oxygen and pulverized coal or any other source of carbon, such as biomass. Carbon-based energy production requires no combustion, allowing it twice the efficiency of traditional coal-fired power plants.

Test questions to be answered:

Question 1: What is the essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

5. Technology:

Vibrating Nano-cantilevers for cancer diagnosis

Description:

Vibrating nano-cantilevers are very tiny and sensitive electromechanical sensors that change frequency when they bind to tumour cells. Given their small size, nano-cantilevers are more sensitive to minute quantities of contaminants associated with conditions such as cancer. This could lead to the early diagnosis of cancer.

Test questions to be answered:

Question 1: What is the essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

APPENDIX 10

THE POSTTEST OF TECHNOLOGICAL LITERACY

Test

1. Technology:

Metal Organic Frameworks

Description:

Developing suitable storage media for hydrogen is critical to capitalizing on the gas's potential benefits as an energy carrier. Among other candidates, the metal-organic framework compound MOF-177 is being studied for its superior gas uptake and storage capability, thanks to the fact that it has a significantly larger surface area and hence better storage capacity than any other porous material reported to date.

Test questions to be answered:

Question 1: What is the essence of this technology?

Question 2: What is the main output?

Question 3: How does the way of handling contribute to higher efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

2. Technology:

Light-emitting diodes

Description:

Light-emitting diodes [LEDs] are more efficient than incandescent bulbs, but they are not bright enough to use indoors. Scientists have now increased brightness of LEDs by punching tiny, nanoscale holes into their surfaces, allowing more light to shine through.

Test questions to be answered:

Question 1: What is the essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

3. Technology:

Circulating Tumor Cell Chip

Description:

A silicon chip with the size of a business card is etched with 78 000 tiny posts, each coated with antibodies that attract rare circulating tumour cells (CtCs). When the patient's blood is pumped through the chip, red and white blood cells bounce past the posts and escape, while CTCs stick for early cancer diagnostics.

Test questions to be answered:

Question 1: What is the essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

4. Technology:

Microscopic Carbon Nanotubes

Description:

By coating a microscopic carbon nanotube with a layer of fuel and igniting one end with a laser, engineers at MIT are able to send a wave of heat through the tube's interior. This thermal wave pushes the electrons in its path which generates a significant electric current. Prototypes have energy density's 100 times greater than that of lithium-ion batteries and are able to store their energy loads indefinitely without leaking charge.

Test questions to be answered:

Question 1: What is the essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

5. Technology:

Colour-changing Polymers

Description:

Researchers at the University of Illinois have developed a polymer that changes colour when overstressed. This will help to alert maintenance and safety workers to structural weaknesses in places such as bridge support, aircraft wings and parachute cords where stress signals play a critical role in repairs and maintenance.

Test questions to be answered:

Question 1: What is the essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

6. Technology:

The Dandelion plant

Description:

The white liquid that seeps from a broken Dandelion stalk, until now seen as a weed, contains an enzyme that causes rapid polymerization and subsequent hardening. Researchers at the Fraunhofer Institute in Germany have found that when this enzyme is chemically removed, the Dandelion produces five times more latex, ready for rubber production.

Test questions to be answered:

Question 1: What is the essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

7. Technology:

Injectable Multi-functional Nanoparticles

Description:

Remotely controlled nanoparticles release drugs to attack tumors when pulsed with an electromagnetic field. This could lead to the targeted treatment of cancer, protecting surrounding tissue and organs from collateral damage associated with conventional methods.

Test questions to be answered:

Question 1: What is the essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

8. Technology:

Ultra-capacitors

Description:

A breakthrough barium-titanate design for ultra-capacitors may soon lead these devices to replace batteries in electrical cars, because they have longer life spans, have no chemical reactions or loss of battery memory and last far longer.

Test questions to be answered:

Question 1: What is the essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

9. Technology:

Metabolomics

Description:

The Human Metabolome Project is a database of 8000 naturally occurring metabolites which are involved in chemical reactions in the human body. The database also contains signatures for 1450 drugs, 1900 food additives and 2900 toxins and now presents this data towards cheap and instant analyses of patients' metabolomic profiles.

Test questions to be answered:

Question 1: What is the essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

10. Technology:

Energy-saving Drywall

Description:

A new type of energy-saving drywall promises to keep houses cooler in summer and hotter in winter. National Gypsum's ThermalCore drywall is embedded with microscopic spheres of paraffin wax that melt when the indoor temperature exceeds 23 degrees and solidify when it cools below that temperature. This phase change allows the walls of homes and other structures to absorb excess heat during the day and to release it during the evening.

Test questions to be answered:

Question 1: What is the essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

APPENDIX 11
THE PRETEST ANSWER SET

1. Device:

Organic Solar Concentrator

Description:

The Organic Solar Concentrator prevents sunlight from being wasted by guiding light photons to solar cells at the edges of organic-dye-tinted plates, improving the intrinsically expensive mechanics of conventional sunlight collection and increasing the efficiency of existing solar panels by up to 50 percent.

Test:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

Answer 1: This technology channels incoming sunlight to solar cells where it is converted. I am looking for a statement containing words such as improvement of efficiency of solar panels / solar energy collection.

Answer 2: This technology acts upon energy to transport it.

Answer 3: Solar cells on organic-dye-tinted plates collect sunlight energy better than traditional solar panels. Thanks to the working of the Organic Solar Concentrator which guides sunlight to these dye-tinted plates, more sunlight per unit area is collected than with conventional systems.

Answer 4: Respondent must at least mention any of a number of formal classification schemes and attempt to fit this technology into such a scheme. Best answer is the cell for transmitting energy.

2. Device:

High efficiency lithium-ion cells

Description:

Whereas the current generation lithium-ion batteries can only sustain a few hundred charge-and-discharge cycles, the next generation lithium-ion batteries can sustain 1000 cycles without loss of cell capacity over time. Given the potential this holds towards more efficient battery life management for the portable electronics industry, Hewlett Packard concluded a deal to collaborate on this technology with innovator Christina Lampe-Onnerud's Boston Power.

Test:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

Answer 1: The new generation lithium-ion cells present a new threshold for charge-and-discharge cycles. I am looking for terms “greater efficiency” in battery life management.

Answer 2: This technology acts upon energy to store it.

Answer 3: The new generation lithium-ion cells are able to sustain portable battery much longer than the current generation does.

Answer 4: Respondent must at least mention any of a number of formal classification schemes and attempt to fit this technology into such a scheme. Best answer is the cell for keeping energy.

3. Device:

Flexible Display

Description:

Polymer Vision’s *Readius* is the first mobile device with a screen bigger than the device itself. The device uses a paper-thin rollable display incorporating electronic ink to display information. This small electronic device is easily carried and stored, but it presents the functionality and user-friendliness of a large electronic display.

Test:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

Answer 1: The Readius overcomes the display constraints of small information devices by incorporating a rollable display. Looking for a statement which shows to me that the respondent understands there is a change in operating principle and that a constraint is conquered. From fixed to rollable display. More information than would be allowed by a small fixed display.

Answer 2: This technology acts upon information to transport it.

Answer 3: The Readius presents a force multiplier in the sense that it is a small device with information display capacity beyond its physical constraints.

Answer 4: Respondent must at least mention any of a number of formal classification schemes and attempt to fit this technology into such a scheme. Best answer is the cell for sending information.

4. Device:

Direct carbon fuel cell

Description:

A new generation of “direct carbon” fuel cells avoid hard to produce hydrogen by sourcing their energy from an electrochemical reaction between oxygen and pulverized coal or any other source of carbon, such as biomass. Carbon-based energy production requires no combustion, allowing it twice the efficiency of traditional coal-fired power plants.

Test:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

Answer 1: Direct carbon fuel cells generate energy with the electrochemical reaction between oxygen and carbon. Avoid hydrogen economy. Avoid combustion, cleaner energy with biomass as input.

Answer 2: This technology acts upon energy to process it.

Answer 3: Direct carbon fuel cells present two benefits with obvious advantages over competing energy sources, i.e. it avoids expensive hydrogen and it requires no combustion.

Answer 4: Respondent must at least mention any of a number of formal classification schemes and attempt to fit this technology into such a scheme. Best answer is the cell for generating energy.

5. Device:

Vibrating Nano-cantilevers for cancer diagnosis

Description:

Vibrating nano-cantilevers are very tiny and sensitive electromechanical sensors that change frequency when they bind to tumour cells. Given their small size, nano-cantilevers are more sensitive to minute quantities of contaminants associated with conditions such as cancer. This could lead to the early diagnosis of cancer.

Test:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Altogether, in which cell of the functionality grid does this technology belong?

Answer 1: Nano-cantilevers are sensitive enough to change their frequency when they identify cancerous cells. Principle of operation and small size are dealbreakers.

Answer 2: This technology acts upon information to transport it.

Answer 3: Given their specific physical attributes, nano-cantilevers may be sent into the human body to help with early diagnosis of cancer. Early detection is a deal breaker.

Answer 4: Respondent must at least mention any of a number of formal classification schemes and attempt to fit this technology into such a scheme. Best answer is the cell for sending information.

APPENDIX 12
THE POSTTEST ANSWER SET

1. Device:

Metal Organic Frameworks

Description:

Developing suitable storage media for hydrogen is critical to capitalizing on the gas's potential benefits as an energy carrier. Among other candidates, the metal-organic framework compound MOF-177 is being studied for its superior gas uptake and storage capability, thanks to the fact that it has a significantly larger surface area and hence better storage capacity than any other porous material reported to date.

Test:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: How does the way of handling contribute to higher efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

Answer 1: MOF-177 may serve as a storage medium for hydrogen, thanks to its superior gas uptake and storage capability. Focus on storage of hydrogen.

Answer 2: This technology acts upon matter to store it.

Answer 3: Better gas uptake and storage capacity. Surface area relative to size, hydrogen economy.

Answer 4: Cell for holding substances.

2. Device:

Light-emitting diodes

Description:

Light-emitting diodes [LEDs] are more efficient than incandescent bulbs, but they are not bright enough to use indoors. Scientists have now increased brightness of LEDs by punching tiny, nanoscale holes into their surfaces, allowing more light to shine through.

Test:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

Answer 1: LEDs may soon shine bright enough to use indoors, thanks to nanoscale holes in their surfaces.

Answer 2: This technology acts upon energy to transport it.

Answer 3: Brighter shining LEDs may replace incandescent bulbs indoors, using much less energy.

Answer 4: Cell for transmitting energy.

3. Device:

Circulating Tumor Cell Chip

Description:

A silicon chip with the size of a business card is etched with 78 000 tiny posts, each coated with antibodies that attract rare circulating tumour cells (CtCs). When the patient's blood is pumped through the chip, red and white blood cells bounce past the posts and escape, while CTCs stick for early cancer diagnostics.

Test:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

Answer 1: This chip processes blood to distinguish healthy blood cells from tumour cells.

Answer 2: This technology acts upon information to process it.

Answer 3: This technology may help with an easy and early cancer diagnostics, which would help patients to avoid the lengthy and expensive conventional procedures.

Answer 4: Cell for composing information.

4. Device:

Microscopic Carbon Nanotubes

Description:

By coating a microscopic carbon nanotube with a layer of fuel and igniting one end with a laser, engineers at MIT are able to send a wave of heat through the tube's interior. This thermal wave pushes the electrons in its path which generates a significant electric current. Prototypes have energy density's 100 times greater than that of lithium-ion batteries and are able to store their energy loads indefinitely without leaking charge.

Test:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

Answer 1: Microscopic carbon nanotubes present a novel manner of generating and storing energy.

Answer 2: This technology acts upon energy to generate and store it.

Answer 3: Microscopic carbon nanotubes have superior energy densities in comparing to existing technologies and are able to store this energy indefinitely without loss.

Answer 4: Cell for generating energy; cell for keeping energy.

5. Device:

Colour-changing Polymers

Description:

Researchers at the University of Illinois have developed a polymer that changes colour when overstressed. This will help to alert maintenance and safety workers to structural weaknesses in places such as bridge support, aircraft wings and parachute cords where stress signals play a critical role in repairs and maintenance.

Test:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

Answer 1: Colour-changing polymers will help repairs and maintenance crews to be alerted to formation of structural weaknesses.

Answer 2: This technology acts upon information to compose, transport and store it.

Answer 3: Where structures which operate under stress are able to forewarn repairs and maintenance crews of structural weaknesses, corrective actions may be instituted in pre-emptive manner, helping to avoid disastrous breakdowns and failures.

Answer 4: Cell for composing information; cell for sending information; cell for saving information.

6. Device:

The Dandelion plant

Description:

The white liquid that seeps from a broken Dandelion stalk, until now seen as a weed, contains an enzyme that causes rapid polymerization and subsequent hardening. Researchers at the Fraunhofer Institute in Germany have found that when this enzyme is chemically removed, the Dandelion produces five times more latex, ready for rubber production.

Test:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

Answer 1: Bio-engineered dandelion plants provide an alternative source of latex towards rubber production.

Answer 2: This technology acts upon matter to process and store it.

Answer 3: Where demand for rubber is higher than supply, this technology may help to establish an equiibrium in the market. Weed status of the plant may be turned around for it to become a cheap source material for rubber production. Serves as an excellent example of bio-engineering and may help to avoid costly production of synthetic rubber.

Answer 4: Cell for transforming substances; cell for holding substances.

7. Device:

Injectable Multi-functional Nanoparticles

Description:

Remotely controlled nanoparticles release drugs to attack tumors when pulsed with an electromagnetic field. This could lead to the targeted treatment of cancer, protecting surrounding tissue and organs from collateral damage associated with conventional methods.

Test:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

Answer 1: Remote release of drugs for targeted treatment of cancer.

Answer 2: This technology acts upon matter to transport and store it.

Answer 3: Given its small size, remotely controlled nanoparticles are taken straight to cancer cells where they release cancer-fighting drugs.

Answer 4: Cell for moving substances; cell for keeping substances.

8. Device:

Ultra-capacitors

Description:

A breakthrough barium-titanate design for ultra-capacitors may soon lead these devices to replace batteries in electrical cars, because they have longer life spans, have no chemical reactions or loss of battery memory and last far longer.

Test:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

Answer 1: The barium-titanate design for ultra-capacitors may be the solution to the shortcomings of the current generation of batteries in electrical cars.

Answer 2: This technology acts upon energy to store it.

Answer 3: This design may lead to a generation of electrical cars which may be able to travel longer on a single charge, to last longer and to require much less system management and maintenance.

Answer 4: Cell for keeping energy.

9. Device:

Metabolomics

Description:

The Human Metabolome Project is a database of 8000 naturally occurring metabolites which are involved in chemical reactions in the human body. The database also contains signatures for 1450 drugs, 1900 food additives and 2900 toxins and now presents this data towards cheap and instant analyses of patients' metabolomic profiles.

Test:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

Answer 1: The Human Metabolome Project makes available a database of metabolomic signatures which until now were not available to patients.

Answer 2: This technology acts upon information to process, transport and store it.

Answer 3: The Human Metabolome Project presents now one composite view of metabolomic signatures to be found in a single location, which makes makes immediate access and profiling possible.

Answer 4: Cell for composing information; cell for sending information; cell for saving information.

10. Device:

Energy-saving Drywall

Description:

A new type of energy-saving drywall promises to keep houses cooler in summer and hotter in winter. National Gypsum's ThermalCore drywall is embedded with microscopic spheres of paraffin wax that melt when the indoor temperature exceeds 23 degrees and solidify when it cools below that temperature. This phase change allows the walls of homes and other structures to absorb excess heat during the day and to release it during the evening.

Test:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Think of an appropriate technology classification scheme, and then state in which single category of that scheme this technology can best be positioned or classified to promote understanding of this technology and its outputs.

Answer 1: The ThermalCORE drywall stores excess heat and releases it when the temperature lowers to the threshold of 23 degrees.

Answer 2: This technology acts upon matter to transform it. It acts upon energy to process and store it.

Answer 3: These drywalls captures energy which may have gone lost during the day and releases it at night, which means they are more energy efficient than competing, heating and cooling technologies.

Answer 4: Cell for transforming substances; cell for transmitting energy; cell for keeping energy.

APPENDIX 13

PLACEBO FOR CONTROL GROUP – QUANTITATIVE EXPERIMENT

A Step Forward for Microbial Machines

A novel approach to genetic engineering could aid in the creation of fuel-producing bacteria--and edge closer to artificial life.

Emily Singer

8/21/2009

In a deft act of genomic manipulation, researchers at the J. Craig Venter Institute, in Rockville, MD, transplanted a bacterial genome into yeast, altered it, and then transplanted it back into a hollowed bacterial shell, producing a viable new microbe. The technique may provide a way to more easily genetically engineer organisms not commonly studied in the lab and could aid in the expanding effort to create microbes that can produce fuels or clean up toxic chemicals. "This research enhances our capabilities in genome engineering and opens new applications," says Jim Collins, a bioengineer at Boston University, who was not involved in the research. "I see this as an important advance relevant to the bioenergy and biomaterials industries".

Thanks to decades of scientific research, microbes such as yeast and E. coli come with an arsenal of genetic tools that have enabled researchers to enact genetic overhauls of increasing complexity--replacing entire chemical pathways, for example, to make microbes that can perform more complex tasks or produce materials more efficiently. But many microbes of industrial interest, such as those with unique capabilities for generating chemicals, aren't as easily hackable. Target organisms include photosynthetic microbes, which scientists hope can be engineered to efficiently turn light into fuel. By inserting the genomes of these bacteria into yeast, the researchers at the Venter Institute are more easily able to engineer them. "People want the capability of yeast or E. coli but want to have the photosynthetic apparatus there," says David Berry, a partner at Flagship Ventures and the 2007 TR35 innovator of the year. "Combining those two genomes would be interesting in the biofuels world".

The new technology emerged from the Venter Institute's high-profile quest to create life from scratch--generating a synthetic genome and then using it to control, or reboot, a recipient cell. In 2007, Venter researchers published a paper describing a genome transplant, in which a genome from one type of bacteria was transferred to a closely related one, giving the host the characteristics of its donor. Then, last year, the researchers created a synthetic genome by stitching together pieces of synthesized DNA.

To build a synthetic organism, however, researchers will have to transplant that synthetic genome into a cell and have it successfully reboot the cell. But that last step has proved problematic. The synthetic genome was assembled in yeast, which means it lacked some of the molecular markings characteristic of bacteria. Researchers discovered that without those markings, the host bacterium viewed the transplanted genome as a foreign invader and destroyed it.

The new technique, published online in the journal Science, provides a way around that hurdle. Sanjay Vashee and colleagues first transplanted the genome of Mycoplasma mycoides into yeast. While scientists had previously grown pieces of bacterial DNA in yeast, this is the first instance of growing an entire bacterial genome this way. Using existing tools for genetically engineering yeast, researchers then chemically altered the bacterial genetic material so that it carried the molecular markings characteristic of bacteria. They transplanted the modified genome into Mycoplasma capricolum, a species closely related to the mycoides genome donor, to create a viable mycoides cell.

The researchers now aim to test the technique on other bacteria. "We want to start transferring this technology to organisms that are more relevant industrially or for biofuels," says Vashee. For example, he says, genetic pathways from organisms that can break down environmental pollutants could be engineered into bacteria that could survive in harsh and contaminated environments, such as acidic ponds, and then used to clean up those areas.

The technology will likely find its way to Synthetic Genomics, a biofuels start-up founded by Venter that is developing genetically modified algae to produce fuels and other chemicals. The company announced a $300 million partnership with ExxonMobil last month.

APPENDIX 14

REQUEST FOR PARTICIPATION IN PILOT EXERCISE

From: Ferdie Lochner

Sent: Sunday, May 09, 2010 11:58 AM

Subject: Request to participate in a pilot measurement for research about technology understanding

Dear colleague

Your name was proposed as a potential respondent for participation in a pilot measurement which tests the power of an academic model to help us become technologically literate. Kindly allow me the opportunity to explain my objectives with this email.

Browsing the business section of popular magazines and weekly papers, one sees short abstracts of novel technologies. There are exceptions to the rule, but most of us tend to skim over these technologies before we proceed to read what we understand and enjoy. Significant investments have however gone into any particular technology for it to be publicized in a popular magazine. These technology investments typically are spurred by those companies and asset management houses which are the custodians of our life savings. Directly or indirectly, we are therefore technology decision-makers, and my PhD research at the University Stellenbosch Business School examines a model known as the *functionality grid* in order to assess its theoretical bona fides and its practical knowledge creating capacity.

Please consider to participate and reply to this email with a simple *yes* or *no*, in order to let me know your preference by Friday, 14 May 2010, end of day. Should you know of more colleagues who may be inclined to assist, please forward these names to me. The only requirements are a formal three or four year university degree and at least five years of work experience.

Finally, this exercise indeed deals with technologies introduced in the South african version of the *Popular Mechanics* magazine of the past 18 months and will require approximately an hour of your time. All the material is in electronic format and stored on our *Intranet*. Should you agree to participate, you will receive further instructions within the foreseeable future.

Sincerely yours

Ferdie Lochner
Head: IT Finance
Information Systems and Technology
City of Cape Town

+27 21 9703645 (Office)
+27 21 9703644 (Fax)
+27 84 444 3643 (Mobile

APPENDIX 15

DIFFICULTIES FINDING PARTICIPANTS FOR PILOT EXERCISE

From: XXXX

Sent: Monday, May 17, 2010 3:00 PM

To: Ferdie Lochner

Subject: RE: Resend: Request to participate in a pilot measurement for research about technology understanding

Hello Ferdie

Can you please indicate when this hour will be required? At the moment my schedule is anything but friendly in terms of accepting additional tasks, but I would want to assist if at all possible.

Regards

XXXX

Director: Library & Information Services

Community Services

City of Cape Town

Tel: +27 21 400-3782

Fax: +27 86 576 1398

Mobile: +27 84 211 2119

E-mail: xxxx

Website: www.capetown.gov.za

From: Ferdie Lochner

Sent: Friday, May 14, 2010 7:48 AM

To: Ferdie Lochner

Subject: Resend: Request to participate in a pilot measurement for research about technology understanding

Dear colleague

I need five more candidates. Please bear with me in repeating my request in the above regard.

Request:

Your name was proposed as a potential respondent for participation in a pilot measurement which tests the power of an academic model to help us become technologically literate. Kindly allow me the opportunity to explain my objectives with this email.

Browsing the business section of popular magazines and weekly papers, one sees short abstracts of novel technologies. There are exceptions to the rule, but most of us tend to skim over these technologies before we proceed to read what we understand and enjoy. Significant investments have however gone into any particular technology for it to be publicized in a popular magazine. These technology investments typically are spurred by those companies and asset management houses which are the custodians of our life savings. Directly or indirectly, we are therefore technology decision-makers, and my PhD research at the University Stellenbosch Business School examines a model known as the *functionality grid* in order to assess its theoretical bona fides and its practical knowledge creating capacity.

Please consider to participate and reply to this email with a simple *yes* or *no*, in order to let me know your preference by Friday, 14 May 2010, end of day. Should you know of more colleagues who may be inclined to assist, please forward these names to me. The only requirements are a formal three or four year university degree and at least five years of work experience.

Finally, this exercise indeed deals with technologies introduced in the South african version of the *Popular Mechanics* magazine of the past 18 months and will require approximately an hour of your time. All the material is in electronic format and stored on our *Intranet*. Should you agree to participate, you will receive further instructions within the foreseeable future.

Sincerely yours

APPENDIX 16

PILOT TEST

Example

Flexible Display (Popular Mechanics, February 2008:32)

Description:

Polymer Vision's *Readius* is the first mobile device with a screen bigger than the device itself. The device uses a paper-thin rollable display incorporating electronic ink to display information. This small electronic device is easily carried and stored, but it presents the functionality and user-friendliness of a large electronic display.

Evaluation:

Question 1: What is the basic essence of this technology?

Answer 1: The Readius overcomes the display constraints of small information devices by incorporating a rollable display.

Question 2: What is the main output?

Answer 2: This technology acts upon information to transport it.

Question 3: What is the main contribution to efficiency?

Answer 3: The Readius presents a force multiplier in the sense that it is a small device with information display capacity beyond its physical constraints.

Question 4: Altogether, in which cell of the functionality grid does this technology belong?

Answer 4: Cell for sending information.

Positioning this technology in the functionality grid

		Action		
		Process	Transport	Store
Output	Matter (M)	Transforming substances	Moving substances	Holding substances
	Energy (E)	Generating energy	Transmitting energy	Keeping energy
	Information (I)	Composing information	Sending information	Saving information

Test

Technology 1:

Zirconium Dioxide

Description:

Zirconium Dioxide (zirconia) is a chemical compound which converts sand and other corrosive materials into a new protective coating, for example, on the turbine blade of a jet engine. Zirconia chemically converts sand and other corrosive particles that build up on the turbine blade into a new, protective outer coating - which means the surface of the blade constantly refreshes itself.

Evaluation:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Altogether, in which cell of the functionality grid does this technology belong?

Technology 2:

Horizontal drilling

Description:

Major reserves of natural gas in the USA are inaccessible, because deep and dense rock slows its flow and makes it impossible to access these sources of energy with traditional vertical drilling. The cost of a barrel of oil has sped up the introduction of new technology which makes possible horizontal drilling for tapping these gas deposits. In practice, the drill goes down vertically until it strikes the rock, and it then makes a 90 degree turn through the rock to reach the gas deposits.

Evaluation:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Altogether, in which cell of the functionality grid does this technology belong?

Technology 3:

Shape-Memory Alloy

Description:

Shape-memory metals "remember" their original cold, forged shape and return to that shape after being deformed by applying heat. General Motors and California-based Dynalloy developed a process to produce a nickel-titanium shape-memory alloy capable of repeating millions of heat-cool cycles. Now that the material can be produced in mass, the heat-cool cycles can be used to tap energy lost via car exhausts so as to spin pulleys for energy generation.

Evaluation:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Altogether, in which cell of the functionality grid does this technology belong?

Technology 4:

Acoustic hyperlens

Description:

The diffraction limit means that images of things smaller than their own sound's wavelength cannot become visible. Magnifying a detailed but short-lived portion of the sound wave, the acoustic hyperlens now produces images of objects 6,7 times smaller than their own sound's wavelength. Such detailed resolution could revolutionize the use of medical ultrasound and naval sonar systems.

Evaluation:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Altogether, in which cell of the functionality grid does this technology belong?

Technology 5:

Revolutionized GSM base station

Description:

Indian Telecoms company VNL produces a solar-powered GSM (Global Systems for Mobile communication) base station which requires less than 100 watts of power to run and costs only $15000, versus the industry standard GSM base station which requires 3000 watts of power and costs $100,000. It is profitable at only $2 of revenue per user per month and is viable in villages with only 100 users. The VNL base station is already available to the Developing World market.

Evaluation:

Question 1: What is the basic essence of this technology?

Question 2: What is the main output?

Question 3: What is the main contribution to efficiency?

Question 4: Altogether, in which cell of the functionality grid does this technology belong?

APPENDIX 17

REVIEW QUESTIONNAIRE FOR PILOT TEST

Review Questions

1. Which of the following alternatives did you use to study the formal lecture before you completed the test?

   Slide presentation with audio track — Slide presentation with text notes

   Combination of audio track and text notes

2. Where you have used the following alternatives, please indicate whether they have contributed to your understanding of the topic under discussion?

Slide presentation with audio track	Yes	No
Slide presentation with text notes	Yes	No
Combination of audio track and text notes	Yes	No

3. Approximately how long did it take you to study the presentation? Tick one option only.

   30 minutes or less — Between 30 and 60 minutes

   Between 60 and 90 minutes — More than 90 minutes

4. Approximately how much time did you spend completing the subsequent test? Tick one option only.

   30 minutes or less — Between 30 and 60 minutes

   Between 60 and 90 minutes — More than 90 minutes

5. Were the instructions towards completion of the exercise clear and unambiguous?

   Yes — No

6. Do you think you have now a better understanding of the basic tenets of technology?

   Yes — No

7. Please give your overall impression about this exercise?

   Positive — Negative

APPENDIX 18

FINAL INSTRUCTIONS FOR PILOT STUDY

From: Ferdie Lochner

Sent: Saturday, May 15, 2010 6:26 PM

To: Ferdie Lochner; Rias van Wyk (vanwyk@technoscan.com)

Subject: Ferdie Lochner - Pilot study - Instructions

Instructions

1. Although it is meant to eventually have practical outcomes, this pilot study remains part of an academic exercise with all of its accompanying jargon, in spite of best effort to avoid these. Your trouble in helping me is therefore deeply appreciated.

2. The total exercise consists of the following sequence: 1) study the formal lecture to learn how a model known as the functionality grid helps you to understand the basic tenets of technology 2) complete the test to assess the effect of the lecture upon your understanding of technology 3) complete the evaluation questions to help me refine the research instrument.

3. By virtue of the fact that you agreed to participate, you have received rights to the relevant Intranet site where the research material is stored. This site is to be found at the following location: http://cityworkspaces.capetown.gov.za/sites/tech/default.aspx. Your material is to be found under the heading **Technology.**

4. Find at this site the formal lecture which you have to study in the format of a slide presentation, the test you have to do in the form of an MS Word document and the short evaluation you have to complete after the test, also in the form of an MS word document.

5. The primary presentation is titled Formal Lecture. This size of this file is 7 Mb and it may take some time to download, because it consists of an audio track as well. To download, point your mouse to the file, double click left and wait for the download to complete. When you have completed the download, follow the next sequence to view the presentation and listen to the audio track:

    a) In the main menu, go to **View** and click on **Slide Show**. Sit back and listen, because the slide show is set on automatic and should run through to the end.

    b) Should you not be able to listen to the audio track, you have two alternatives.

        i) To read on your screen the text accompanying the slide presentation, go to **View** In the main menu, and click on **Notes Pages**. Read the text explaining every slide and scroll down at your own leisure.

ii) To print out the entire presentation together with the text notes, go to **File**, **Print** and select **Notes Pages** under **Print What**.

6. You also have the option to print out the text notes and to listen to the audio track while you follow the presentation on the printed text notes. This alternative is strongly recommended towards internalization of the study material.

7. When you have studied the content of the formal lecture, please download the test titled Test, hit the white Edit Document button at the top of the screen and proceed to study the example marked as **Example** before you complete on your screen the test under the heading **Test.** The test consists of five technology descriptions, each followed by a set of four questions. This is an open book test and you are encouraged to consult the learning material during the test.

8. When you have completed the test, please download the short evaluation survey titled Review Questions, hit the white Edit Document button at the top of the screen and complete the the survey consisting of 7 questions. In this instance, you simply have to tick off your preferred response among the options provided. Your responses to these questions are meant to help refine this research instrument for the final data collection process.

9. When you have completed the test and the subsequent evaluation, please save the documents under the same names and submit your electronic documents [test and evaluation] to Ferdie.lochner@capetown.gov.za.

10. Should you have any problem in completing the exercise, please do not hesitate to contact me at any time. If I cannot take your call, please leave a message. I will respond as soon as the opportunity arises to do so.

11. **You have to complete the entire exercise within 24 hours after you have started it**.

12. **Please complete and submit the full exercise not later than Monday morning, 24 May 2010 at 0800 AM.**

APPENDIX 19

REQUEST TO USE USB MBA STUDENTS AS RESPONDENTS IN EXPERIMENT

January 12, 2010
Prof. Frikkie Herbst
Head: Doctoral Programme;
University of Stellenbosch Business School
P.O. Box 610,
Bellville 7535

Dear Professor Herbst:

PH.D. CANDIDATE FERDIE LOCHNER: CLASSROOM EXERCISE

Mr. Ferdie Lochner has reached an important stage in his Ph.D. research. He has completed the theoretical background and is now in the position to put his theory to the test.

He has planned a number of exercises including (i) Structured interviews with MOT practitioners. (ii) A test of competence, comparing people who have had exposure to aspects of MOT theory to people who have not. (iii) A test of literacy comparing the insight of people who have been theoretically briefed, to the insights of control groups who have had little or no exposure.

For cases (ii) and (iii) Mr. Lochner requires the voluntary cooperation of a group of educated people with comparable demographics. I wish to request that he be allowed to work with the MBA class in 2010.

The participants should gain much insight into the theory of MOT, and become more aware of the importance of technological acuity in modern business life. Mr. Lochner will be assured of an educated group of participants, and be spared the effort of recruiting and motivating such a group.

I look forward to a favourable response to this request.

Kind regards,

Dr. Rias J. van Wyk
Director: Technoscan® Centre
Web: www.technoscan.com
E-mail: host@technoscan.com
Telephone: 083 255 8436

APPENDIX 20

REQUEST FOR PARTICIPATION IN MAIN EXPERIMENT

From: Ferdie Lochner
Sent: Wednesday, June 23, 2010 9:32 AM
To:
Subject: Request for participation in PhD project at USB

F.C. Lochner
9 Kameeldoring Street
Kuils River
7580

22 June 2010

Dear MBA student

This letter seeks your assistance to participate in a research project aimed at a more versatile and streamlined structure for technological knowledge.

In most countries, including South Africa, there is a growing realization that the state of technological knowledge is inadequate to meet the needs of the 21st century. Even advanced countries such as the United States find its citizens not equipped to make well-considered decisions or to think critically about technology. As a society we are not even fully aware of or conversant with the technologies we use every day. At the same time, however, we do already observe the irruption of yet another techno-economic epoch, where we see how respectively Information and Communication Technologies, Nanotechnologies and Biotechnologies converge upon each other to form entirely new applications.

From a management point of view our lack of understanding these technologies curtails our ability to find and harness technology-based innovation opportunities. This ultimately has a retarding effect on the pace of economic growth.

At the USB the need for greater technological literacy among managers is fully acknowledged. So much so that the school has agreed to a research project aimed at a better structure for technological knowledge. This is the theme of my Ph.D.

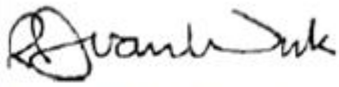
Should you be so kind to agree towards participation, you will receive an email notification that you have been allocated access to the relevant Webstudies module hosting the research material and associated instructions. From here you will be able to download and complete the exercise, which consists of a pretest, a learning intervention and a post-test. Experience gleaned from a pilot study shows that the entire exercise should take between 60 and 90 minutes to complete.

In light of the above, please consider to enlist by sending me a short **Yes** in response to this email.

Your consideration is most sincerely appreciated.

Sincerely yours

PhD student (Ferdie Lochner)



Supervisor (Prof. R.J. Van Wyk)

USB (Prof. F.J. Herbst)

Ferdie Lochner

APPENDIX 21

REMINDER TO COMPLETE EXPERIMENT

From: Ferdie Lochner

Sent: Thursday, July 01, 2010 12:20 PM

To: Ferdie Lochner

Subject: Reminder: request for participation in PhD experiment at USB

Dear Madam / Sir

A week ago I sent you a request to consider participating in my PhD experiment at USB. Allow me to remind you of my request as it appears in its original form just below my email signature. I have had 57 positive responses and have quite a long way to go towards the threshold I am obliged to pursue. Allow me therefore to appeal to you to please consider participation and to let me know. The way this experiment is set up on Webstudies will allow you a two week open period, during which period you have to complete the exercise of between 60-90 minutes within 24 hours. The exercise is to be opened up as soon as I have reached the stated threshold, but not later than 10 July 2010.

Your kind consideration of my request is sincerely appreciated.

Yours faithfully

Ferdie Lochner
Head: IT Finance
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City of Cape Town

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+27 84 444 3643 (Mobile)

Ferdie.lochner@capetown.gov.za

www.capetown.gov.za

MY ORIGINAL REQUEST:

APPENDIX 22

INSTRUCTIONS FOR EXPERIMENTAL GROUP

Instructions: Group A

1. You have agreed to participate in this experiment and to meet its requirements for scientific control and integrity.
2. This experiment is a sequence consisting of a pretest, a formal presentation in the form of a slidecast, and a post-test.
3. When you have studied these instructions, please use your unique password to enter the experiment.
4. When you have entered the experiment, please proceed with the following steps:
   a) First download and then open the document titled "Pretest" and complete the questions which form part of this test. Submit your response when completed.
   b) Secondly, download and study with concentration the slidecast presentation, titled "The Functionality Grid". To this end, participants have at least three options:
      i) In the main menu, go to View and click on Slide Show. Sit back and listen, because the slide show is set on automatic and should run through to the end.
      ii) Should you not be able to listen to the audio track of this slidecast, you have two alternatives.
         1. To read on your screen the text accompanying the slide presentation, go to *View* in the main menu, and click on *Notes Pages*. Read the text explaining every slide and scroll down at your own leisure.
         2. To print out the entire presentation together with the text notes, go to *File*, *Print* and select *Notes Pages* under *Print What*.
      iii) You also have the option to print out the text notes <u>and</u> to listen to the audio track while you follow the presentation on the printed text notes. <u>This alternative is strongly recommended towards proper internalization of the study material.</u>
   c) When you are satisfied that you understand the contents of the formal presentation, please download the document titled "Post-test" and complete the questions which form part of this test. Submit your responses when completed.
   d) When the sequence is completed, please log out.
5. The total experiment is designed to be completed on average within 90 minutes. You have however altogether 24 hours to complete the entire experiment, from the moment you first enter the exercise and start with the pretest to final completion and submission of the post-test. Please note that this measure is purely to help ensure validity of the results.
6. Your cooperation not to share the content of your experiment with your peers or other participants among your peers during the experiment itself is deeply appreciated. This measure, once again, is purely in promotion of validity and you are welcome to share your experience with peers and other participants after the open period has elapsed as per the stated dates and times.
7. This experiment will be open for a four week period, starting on x June 2010 at 24h00 and closing on x July 2010 at 24h00.
8. Should you have any trouble with these instructions and associated material, please contact Ferdie Lochner at Ferdie.lochner@capetown.gov.za.
9. Your cooperation in closely following the above instructions is sincerely appreciated!

APPENDIX 23

INSTRUCTIONS FOR CONTROL GROUP

Instructions: Group B

You have agreed to participate in this experiment and to meet its requirements for scientific control and integrity.

This experiment is a sequence consisting of a pretest, a science-related presentation, and a post-test.

When you have studied these instructions, please use your unique password to enter the experiment.

When you have entered the experiment, please proceed with the following steps:

First download the document titled “Pretest” and complete the questions which form part of this test. Submit your response when completed.

Secondly, download the document titled “A Step Forward for Microbial Machines” and read it with attention.

When you are satisfied that you understand the contents of this document, please download the document titled “Post-test” and complete the questions which form part of this test. Submit your responses when completed.

When the entire sequence is completed, please log out.

The total experiment is designed to be completed on average within 90 minutes. You have however altogether 24 hours to complete the entire experiment, from the moment you first enter the exercise and start with the pretest to final completion and submission of the post-test. Please note that this measure is purely to help ensure validity of the results.

Your cooperation not to share the content of your experiment with your peers or other participants among your peers during the experiment itself is deeply appreciated. This measure, once again, is purely in promotion of validity and you are welcome to share your experience with peers and other participants after the open period has elapsed as per the stated dates and times.

This experiment will be open for a four week period, starting on x June 2010 at 24h00 and closing on x July 2010 at 24h00.

Should you have any trouble with these instructions and associated material, please contact Ferdie Lochner at Ferdie.lochner@capetown.gov.za.

Your cooperation in closely following the above instructions is sincerely appreciated!

APPENDIX 24

NOTICE TO PARTICIPANTS ABOUT START OF EXPERIMENT

From: Ferdie Lochner

Sent: Tuesday, July 13, 2010 4:15 PM

To: Ferdie Lochner

Cc:

Subject: Lochner PhD research module opened up on 14 July 2010

Dear Sir / Madam

Upon my earlier request you agreed to participate in my PhD research experiment. You have now access rights to the ***Lochner PhD Research*** module in Webstudies, which is to be opened up on **14 July 2010**.

Please read the instructions carefully and proceed to complete the exercise which consists of at least 1)a pretest, 2)a lecture type intervention in the form of a short paper or presentation and 3)a post-test. It is of critical importance that you follow this sequence.

Please note the control measures, specifically that you do not share your experiences with your MBA colleagues until you have individually completed the exercise, as well as that you complete the entire exercise within 24 hours after you started it. The module as a whole is opened for a two week period, ending on 28 July 2010 at 2400. Keeping strictly to these measures will help to ensure integrity of the results.

With sincere appreciation!

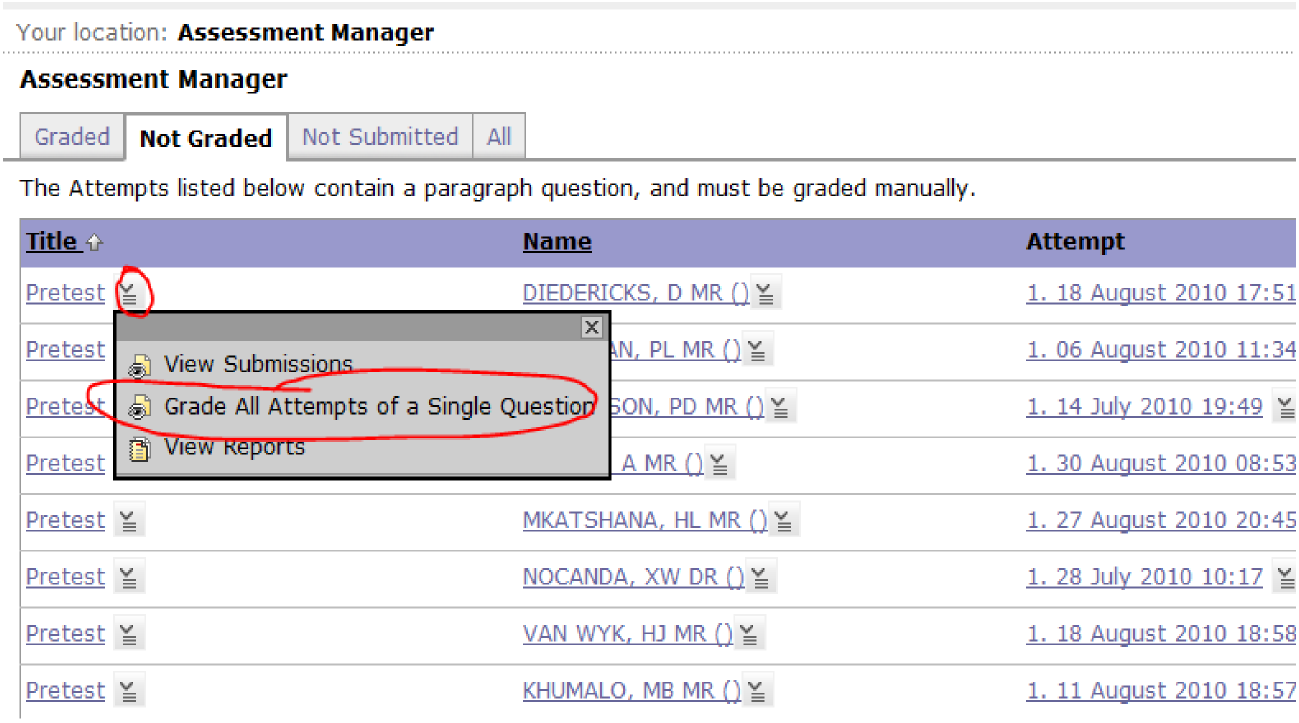
Ferdie Lochner

APPENDIX 25

EXCERPTS FROM WebCT

WebCT Assessment Manager

Source: WebCT, 2010.



WebCT option for grading of all attempts of a single question

Source: WebCT, 2010

APPENDIX 26

EXAMPLES OF FOLLOW-UP MESSAGES TO PARTICIPANTS

From: Ferdie Lochner
Sent: Wednesday, July 28, 2010 3:11 PM
To: Ferdie Lochner
Cc: Scholtz Marsunet BPC
Subject: Lochner PhD research module: Follow-up reminder

Ladies and Gents

Allow me the inevitable follow-up reminder to you to complete my PhD research experiment. The first deadline passes tonight, but I am falling in with your schedules and have arranged for the module to remain open until 12 August 2010. Your trouble in supporting my research project remains much appreciated.

Faithfully yours

From: Ferdie Lochner
Sent: Thursday, July 29, 2010 12:54 PM
To: XXX
Subject: RE: Lochner PhD research module: Follow-up reminder

Hi XXX

From 95 MBAs who agreed to participate, only 25 complied to their undertaking so far. Your apologies are therefore much, much appreciated. I nevertheless appreciate that every MBA is a very busy person and have accordingly provided for delays in my project plan.

Thanks again for your trouble in this regard!

Best regards

Ferdie Lochner
Head: IT Finance
Information Systems and Technology
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+27 84 444 3643 (Mobile)
Ferdie.lochner@capetown.gov.za
www.capetown.gov.za

From: XXX
Sent: Thursday, July 29, 2010 12:49 PM
To: Ferdie Lochner
Subject: RE: Lochner PhD research module: Follow-up reminder

Hi Ferdie, I am terribly sorry having missed your initial deadline. I was travelling and have only just returned so will complete it by tomorrow!

Kind regards

From: Ferdie Lochner
Sent: Tuesday, August 17, 2010 3:13 PM
To: XXX
Subject: RE: Lochner PhD research module: Follow-up reminder

Dear XXX

Thanks so much for your kindness in spite of all your work and study challenges. Your assistance in completing the exercise would indeed be very much appreciated. My deadlines shift every time until I have a workable and defendable data set.

Please let me know when completed and fully submitted?

Many thanks again and best regards

Ferdie Lochner
Head: IT Finance
Information Systems and Technology
City of Cape Town
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+27 21 9703644 (Fax)
+27 84 444 3643 (Mobile)
Ferdie.lochner@capetown.gov.za
www.capetown.gov.za

From: XXX
Sent: Tuesday, August 17, 2010 3:09 PM
To: Ferdie Lochner
Cc: XXX
Subject: RE: Lochner PhD research module: Follow-up reminder

Good Afternoon Ferdie,

Apologies for not being able to complete the exercise before the due date due to various challenges. I am back in the office and could assist if still required.

APPENDIX 27

COPY OF FINAL RESULTS FOR QUANTITATIVE EXPERIMENT

Respondent	Group	Time	Percentage score
1	Control	pretest	20.00
1	Control	posttest	11.25
2	Control	pretest	13.75
2	Control	posttest	11.25
3	Control	pretest	23.75
3	Control	posttest	11.88
4	Control	pretest	21.25
4	Control	posttest	13.13
5	Control	pretest	22.50
5	Control	posttest	14.38
6	Control	pretest	15.00
6	Control	posttest	15.60
7	Control	pretest	32.00
7	Control	posttest	16.25
8	Control	pretest	27.50
8	Control	posttest	16.25
9	Control	pretest	12.50
9	Control	posttest	17.50
10	Control	pretest	20.00
10	Control	posttest	19.38
11	Control	pretest	18.75
11	Control	posttest	21.25
12	Control	pretest	25.00
12	Control	posttest	23.75
13	Control	pretest	18.75
13	Control	posttest	25.63
14	Control	pretest	15.00
14	Control	posttest	26.25
15	Control	pretest	21.25

15	Control	posttest	26.25
16	Control	pretest	26.00
16	Control	posttest	29.38
17	Control	pretest	31.25
17	Control	posttest	30.63
18	Control	pretest	36.25
18	Control	posttest	31.25
19	Control	pretest	46.25
19	Control	posttest	41.25
20	Experimental	pretest	35.00
20	Experimental	posttest	30.63
21	Experimental	pretest	20.00
21	Experimental	posttest	34.38
22	Experimental	pretest	18.75
22	Experimental	posttest	34.38
23	Experimental	pretest	16.25
23	Experimental	posttest	36.25
24	Experimental	pretest	20.00
24	Experimental	posttest	38.13
25	Experimental	pretest	20.00
25	Experimental	posttest	39.38
26	Experimental	pretest	13.75
26	Experimental	posttest	43.75
27	Experimental	pretest	18.75
27	Experimental	posttest	45.63
28	Experimental	pretest	17.50
28	Experimental	posttest	46.25
29	Experimental	pretest	22.50
29	Experimental	posttest	46.25
30	Experimental	pretest	17.50
30	Experimental	posttest	47.50
31	Experimental	pretest	20.00
31	Experimental	posttest	47.50
32	Experimental	pretest	13.75

32	Experimental	posttest	49.38
33	Experimental	pretest	26.25
33	Experimental	posttest	50.63
34	Experimental	pretest	43.75
34	Experimental	posttest	53.13
35	Experimental	pretest	21.25
35	Experimental	posttest	53.75
36	Experimental	pretest	32.50
36	Experimental	posttest	54.38
37	Experimental	pretest	33.75
37	Experimental	posttest	56.25
38	Experimental	pretest	21.25
38	Experimental	posttest	58.75
39	Experimental	pretest	24.75
39	Experimental	posttest	59.38
40	Experimental	pretest	23.75
40	Experimental	posttest	61.25
41	Experimental	pretest	11.25
41	Experimental	posttest	61.25
42	Experimental	pretest	26.25
42	Experimental	posttest	65.00
43	Experimental	pretest	31.25
43	Experimental	posttest	67.50
44	Experimental	pretest	22.50
44	Experimental	posttest	70.00
45	Experimental	pretest	17.50
45	Experimental	posttest	70.00

APPENDIX 28

THE DUAL-NATURE EXPERIMENT – EXPERIMENTAL PARTICIPANT

UNIVERSITY OF STELLENBOSCH BUSINESS SCHOOL

Management of Technology

A Linnaeus Experiment

Ferdie Lochner

6/20/2010

CONTENTS

INSTRUCTIONS

1. Read with attention the short précis enclosed as Addendum A. You have 30 minutes to do so and will be accordingly timed.
2. When you have completed your reading, proceed with following instructions:
   a) Study the descriptions of the five technologies which appear from P.4 onwards.
   b) Then describe the essence of each technology in one sentence only.
   c) Think of any classification scheme, and then show how each technology fits into your specific scheme.
   d) You have 60 minutes to complete this task.
3. When completed, exchange your results with your co-participant , evaluate his/her submission and proceed to answer the following questions:
   a) Describe your co-participant’s submission. Does it resemble a classification scheme of one or another nature? Why do you say so?
   b) How long did it take your co-participant to complete the exercise, i.e. what would be a good estimate?
   c) From observing his/her behavior, did you pick out any structure or systematic method in completing the exercise?
   d) Did he/she appear to be at ease during the exercise?
   e) No time limit applies.
4. When you have completed the above instructions, please hand in your results to your supervisor.

FORMAL TEST

1. Technology:

Nanoyarn

Description:

New Hampshire-based Nanocomp Technologies is weaving nanotubes into lengths of yarn that can be used for commercial applications. They have recently delivered a a nanoyarn of almost ten kilometers to an aerospace company. Until now they have been too difficult to manufacture in useful quantities, but this breakthrough in form factor means nanotubes can be commercially supplied and used for the fact that they are hundred times stronger than steel and conduit both heat and electricity.

2. Technology:

PUR Water Purifier

Description:

A powder called PUR represents a multi-step process for water purification in one single substance, packaged into a small sachet of only a few cents. This helps poor people to inexpensively and at once purify water for residential use.

3. Technology:

Fourth Generation Fuel

Description:

Scientists have genetically engineered algae to turn carbon dioxide into oil and to continuously excrete the oil into the surrounding water. This makes harvesting easy for a biodiesel which uses no fresh water in its production and which yields significantly more energy per unit area than competing biodiesels.

4. Technology:

Tiny Engineered Blood Vessels

Description:

The development of organic cells can now be controlled to form parallel tube-like structures on nanoscale scaffolds. These cells can be bio-engineered to form blood vessels, and they could one day be transplanted to vascular tissue such as the kidney, liver or heart to help movement of nutrients, gases and waste to and from cells.

5. Technology:

Self-healing Materials

Description:

Self-healing materials can be incorporated into hosting materials such as paint, circuit boards or even the concrete in bridges. When the hosting material damages, embedded micro-capsules in the hosting material rupture, which allows a healing agent to seep out and to mix with a catalyst also embedded in the hosting material. The combination hardens and helps the hosting material to repair itself, lessening the chances for catastrophic events.

ADDENDUM A

THE FUNCTIONALITY GRID: A SHORT LECTURE

Technology change

When we think of the general conception of technology, we are able to distinguish several outstanding attributes, two of which are the omnipresence and diversity of technology. An outstanding trait however is the evolution of technology and the inevitable change it brings along. Van Wyk (1979:286; 1989:9; 2009a) sums up these trends as follows:

1. Increasing complexity.
2. Increasing range of size from micro to macro.
3. New principles of operation.
4. Use of new materials.
5. Increasing performance and efficiency:
   a. Outputs achieved in shorter time.
   b. Increase in capacity.
   c. Increase in density.
   d. Increase in accuracy.

Technology functionality

Given these attributes and trends, how are we as technology decision-makers to analyze and understand technology in our business environment? One of the best mechanisms to consider is technology functionality, because functionality more than any other technology trait is intrinsically embedded in technology and its practical manifestations.

The functionality grid

Technology functionality is best captured in the nine cell functionality grid illustrated below:

		Action		
		Process	Transport	Store
Output	Matter (M)	Transforming substances	Moving substances	Holding substances
	Energy (E)	Generating energy	Transmitting energy	Keeping energy
	Information (I)	Composing messages	Sending messages	Saving messages

Source: Van Wyk, 2009b:7.

The functionality grid's essence is to classify all technologies in terms of their pre functional outputs. To this end, the horizontal axle shows whether the output handles matter, energy or information, and the vertical axle shows the way of handling, or action, that is involved, i.e. processing, transportation or storage. Together, these nine cells encapsulate the sum total of physical inputs, kinds of industrial manipulation and technology outputs. The logic of the above appears clearly in the following example, where a new voice processing technology is described with the help of the functionality grid:

		Positioning this technology in the functionality grid		
		Action		
		Process	Transport	Store
Output	Matter (M)	Transforming substances	Moving substances	Holding substances
	Energy (E)	Generating energy	Transmitting energy	Keeping energy
	Information (I)	Composing information	Sending information	Saving information

Source: Adapted from Van Wyk, 2009c.

In following the line of argument demonstrated above, we see how 1) the basic essence of this technology is described, i.e. a new voice processing technology; 2) how its main output is described, i.e. this technology acts upon information to transport it; 3) how it contributes to higher efficiency, i.e. greater clarity, versatility and accuracy of processed voice content in comparison to existing voice processing technologies; and 4) how it finally is positioned in the functionality grid, i.e. in the cell for sending information.

Benefits of the functionality grid

The functionality grid presents a simple and standardized protocol for understanding, describing and classifying technology outcomes. To the technically minded it presents many leads to follow towards more complexity, such as comparing performance of technologies which store versus those that transport. It makes provision for the full continuum of technologies, whether a simple device such as glass bottle, a system such as computer, a platform like an aeroplane or an array like an electricity grid.

To the less technically minded, it presents an immediate and intuitively accessible descriptor of technology, whether it is large or small, simple or complex, new or old. To busy executives, the functionality grid presents a one page overview of the nine pathways of technology perfection. Its nature and appearance is concise, its logic is coherent and its reach is comprehensive. To these executives, it presents easily accessible answers to questions about technology outcomes, i.e.

what are the inputs, what are the manipulating processes, what are the outputs and what performance increasing trends can be anticipated?

References

Van Wyk, R.J. 2009a. Technology assessment for portfolio managers. *Technovation*, **30**, 223–228.

Van Wyk, R.J. 2009b. Technological renewal in the USA: A pivotal role for MOT. Proceedings: 18th International Conference for the International Association for Management of Technology, Orlando, Florida, April 5-9, 2009: Section 16 – Theory of Technology.

Van Wyk, R.J. 2009c. Text to voice. *Technoscan® Newsbrief*, **4**(3), March 31.

Van Wyk, R.J. 1989. *Management of technology – New horizons*. Inaugural Lecture. Cape Town: Graduate School of Business, University of Cape Town.

Van Wyk, R.J. 1979. Technological change: A macro perspective. *Technological Forecasting & Social Change*, **15**(4): 281–296.

APPENDIX 29

THE DUAL-NATURE EXPERIMENT – CONTROL PARTICIPANT

UNIVERSITY OF STELLENBOSCH BUSINESS SCHOOL

Management of Technology

A Linnaeus Experiment

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INSTRUCTIONS

1. Read with attention the short précis enclosed as Addendum A. You have 30 minutes to do so and will be accordingly timed.

2. When you have completed your reading, proceed with following instructions:

   a) Study the descriptions of the five technologies which appear from P.4 onwards.

   b) Then describe the essence of each technology in <u>one</u> sentence only.

   c) Think of any classification scheme, and then show how each technology fits into your specific scheme.

   d) You have 60 minutes to complete this task.

3. When completed, exchange your results with your co-participant , evaluate his/her submission and proceed to answer the following questions:

   a) Describe your co-participant’s submission. Does it resemble a classification scheme of one or another nature? Why do you say so?

   b) How long did it take your co-participant to complete the exercise, i.e. what would be a good estimate?

   c) From observing his/her behavior, did you pick out any structure or systematic method in completing the exercise?

   d) Did he/she appear to be at ease during the exercise?

   e) No time limit applies.

4. When you have completed the above instructions, please hand in your results to your supervisor.

FORMAL TEST

1. **Technology:**

Nanoyarn

Description:

New Hampshire-based Nanocomp Technologies is weaving nanotubes into lengths of yarn that can be used for commercial applications. They have recently delivered a a nanoyarn of almost ten kilometers to an aerospace company. Until now they have been too difficult to manufacture in useful quantities, but this breakthrough in form factor means nanotubes can be commercially supplied and used for the fact that they are hundred times stronger than steel and conduit both heat and electricity.

2. **Technology:**

PUR Water Purifier

Description:

A powder called *PUR* represents a multi-step process for water purification in one single substance, packaged into a small sachet of only a few cents. This helps poor people to inexpensively and at once purify water for residential use.

3. **Technology:**

Fourth Generation Fuel

Description:

Scientists have genetically engineered algae to turn carbon dioxide into oil and to continuously excrete the oil into the surrounding water. This makes harvesting easy for a biodiesel which uses no fresh water in its production and which yields significantly more energy per unit area than competing biodiesels.

4. **Technology:**

Tiny Engineered Blood Vessels

Description:

The development of organic cells can now be controlled to form parallel tube-like structures on nanoscale scaffolds. These cells can be bio-engineered to form blood vessels, and they could one day be transplanted to vascular tissue such as the kidney, liver or heart to help movement of nutrients, gases and waste to and from cells.

5. **Technology:**

Self-healing Materials

Description:

Self-healing materials can be incorporated into hosting materials such as paint, circuit boards or even the concrete in bridges. When the hosting material damages, embedded micro-capsules in the hosting material rupture, which allows a healing agent to seep out and to mix with a catalyst also embedded in the hosting material. The combination hardens and helps the hosting material to repair itself, lessening the chances for catastrophic events.

ADENDUM A

CAN CRAIG VENTER'S SYNTHETIC LIFE ACCELLERATE ALGAU FUELS?

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The last ten days have been hectic for those in the genetic engineering field. Synthetic life has been created, scream the headlines, and well, it is no hoax, at least not entirely. The man at the center of it all, Craig Venter, is no stranger to those in the field of biotech, having been associated earlier with mapping the human gene.

Such a breathtaking announcement is not just of academic interest to us at Oilgae, because Venter has reportedly mentioned that the first real-world use to which he plans to try his synthetic life creation technique will be in – hold your breath – algae fuels.

Exxon Mobil entered into a partnership with Craig Venter's Synthetic Genomics (SGI) in mid 2009 in order to explore applying SGI expertise in genetic engineering to create algae that can produce biofuels on a large scale, in an economically sustainable manner. While ExxonMobil brings in the engineering expertise and tons of money, SGI brings in the genetic engineering knowledge. Exxon Mobil had committed to invest over $600 million in this effort to make sustainable algae fuels a reality.

Now you can well understand why all of us here at algae have been burning our midnight oil last one week over Craig Venter's work. Well, we have been following Craig Venter since the time Exxon Mobil invested in his company, but his recent achievement added an extra level of importance to his work for all of us at Oilgae.

I hence thought that I'd dedicate this issue of the newsletter to providing inputs and perspectives on Craig Venter's work and how it could influence algae fuel research.

The following are the sections in this detailed article:

1. Background of Craig Venter and his recently breakthrough.

2. Critical challenges in algae fuels

3. How genetic engineering could help overcome these challenges

Craig Venter – Background and Recent Breakthrough

John Craig Venter is an American biologist and entrepreneur, most well-known until recently for his role in being the (joint) first to sequence the human genome. Two weeks back, he became equally famous for booting up the first living cell with a synthetic genome.

Venter has been a founder of companies/organisations such as Celera Genomics, The Institute for Genomic Research, the J. Craig Venter Institute and Synthetic Genomics. He was listed on Time magazine's 2007 and 2008 Time 100 list of the most influential people in the world.

His work on human genome

Craig Venter isn't exactly your idea of a normal human being. Far from it. While working on the project to map the human genome, Craig Venter believed that the maverick approach of shotgun sequencing (rather than a classical long-winded approach) was the fastest and most effective way to get useful human genome data. The method was controversial since some geneticists felt it would not be accurate enough for a genome as complicated as the human.

With funding from the private sector, Venter founded Celera Genomics, whose goal was to sequence the entire human genome and release it into the public domain for non-commercial use in much less time and for much less cost than the public human genome project. DNA from five demographically different individuals was used by Celera to generate the sequence of the human genome, one of them being Venter himself!

In 2000, Venter and Francis Collins of the National Institutes of Health and U.S. Public Genome Project jointly made the announcement of the mapping of the human genome. Despite some claims that shotgun sequencing was in some ways less accurate than the clone-by-clone method chosen by the Human Genome Project, the technique became widely accepted by the scientific community and is still used today.

After the human genome project, Venter founded - and is the president of - the J. Craig Venter Institute, which conducts research in synthetic biology. In June 2005, he co-founded Synthetic Genomics, a firm dedicated to using modified microorganisms to produce clean fuels and biochemicals.

The first synthetic life form

In May 2010, a team of scientists led by Venter became the first to successfully create what was described as "synthetic life".

Craig Venter and his team had succeeded in building the genome of a bacterium from scratch and had incorporated it into a cell to make what they called the world's "first synthetic life form”.

How exactly did they do this?

In a decade-long work, Venter and his researchers first mapped the genome of a simple bacteria, Mycoplasma mycoides. A genome is the 'brain' and control center of a cell, and contains sequences of DNA which carry all the genetic information needed for the cell — and by extension, the organism — to function. Genomes, like all other living matter, are made of chemical compounds.

Once the genome was mapped, Venter’s team manufactured the M. mycoides' genome in the lab, using chemicals. This synthetic genome was identical to the 'original' except for certain harmless 'signatures' the team put in to identify it as synthetic. The synthetic genome was then inserted into another type of bacteria after the bacteria's own genome had been taken out.

Voila! As soon as the synthetic genome was inserted into the genomeless cell, it started making new proteins encoded in its DNA and converted it into a new synthetic species. That is, the cell was able to understand the synthetic genome and started "working with it". According to Craig Venter, the cell has replicated over a billion times, and the only DNA that the cell has now is the synthetic one that Venter’s team made. Exciting stuff!

(For trivia buffs, the new organism has been nicknamed Synthia, and the Mycoplasma mycoides bacterium causes mastitis in goats.)

Is this really an example of synthetic life? Not everyone agrees. For instance there are some who - in my opinion, correctly - point out that Craig Venter did not create a live cell, he only created an artificial part of the cell which integrated itself nicely with the existing cell. And then there are others who say that the synthetic cell achievement does not fully demystify life's underlying code, the genome. They claim that the researchers built much of the bacterium's genome without fully understanding the function of many of the million-plus base pairs involved. About half of the genes, in fact, are still "a complete black box," said Richard Roberts of New England Biolabs, Inc., in a commentary after Venter's talk. (Source: http://bit.ly/ahSN4Z). In order words, some of these experts feel that it is a fairly dumb reconstruction of an existing design, with no clue of what the components of the design mean.

They might have a point after all. In an earlier instance, when the team had got just one piece out of the millions of pieces wrong, the genome simply did not work. And well, this also does not mean that the team has the ability to create a genome that is original. In fact, some experts feel that the technical expertise and understanding required to create an entire, original cell might take a long, long time – long after you and I are dead and gone.

Leaving aside these technical points, a more pertinent question for us at Oilgae is: Whether or not this event qualifies as a “synthetic life creating event”, what consequences does it hold for the future of algae fuels? If scientists do not fully understand what component of genome does what but only have a “black box” understanding, isn’t their capability restricted to simply making copies of existing genomes without being able to create absolutely original ones? If that is indeed so, and all they do is to “synthetically” produce a genome that already exists in some other algal strain, isn’t it easy to simply “extract” the genome from that desired strain than painstakingly create it in the lab? Put another way, is this experiment by Venter only of academic interest or does it make a practical difference?

I had a lengthy discussion on this with my biotech team-mates, and they assured me that this event can make a practical difference.

A bit of reading helped me to identify the following advantages that synthetic genes have over their natural counterparts:

1. They are obtained more quickly and less expensively than conventionally cloned genes.
2. They are simple to modify in order to facilitate downstream manipulations.
3. Any sequence you wish is possible.

To illustrate the advantages mentioned above, just because scientists have identified a desired genome in an algal strain does not mean that they will be able to extract the natural genome exactly the way they would wish to. Under such circumstances, it is worth creating the genome artificially because you can get it exactly the way you want it. Such control alone, my colleagues pointed out, could make an enormous difference.

Interesting indeed. So, I asked myself, in what specific aspects could genetic engineering, armed with this added capability to create synthetic genomes, influence algae biofuels? In order to answer this question, I first started with the critical challenges faced by the algae fuels industry.

Critical challenges in algae fuels

While a number of hurdles stand in the way of sustainable algae fuels, the following are, in my opinion, the key hurdles:

1. It is difficult to selecting a suitable algae strain/species with high productivity and oil content, which can also grow well in specific environments.

2. High cost of cultivation. This includes costs for mixing, CO2 (if sourced from outside), aeration, nutrients, labour and other general maintenance costs, and amortized capital costs.
3. High cost of harvesting algae from the growth medium
4. High costs for drying.

Some of you might point out that there are challenges in oil extraction (owing to the tough cell walls) as well as in transesterification (owing to the high FFA content), but I reckon these are not as critical and difficult as the ones noted above.

When genetic engineering meets the algae fuel challenges…

Let's look at each of the challenges and explore how genetic engineering could help overcome the challenge.

"Creating" optimal algae strains

This will probably be the area where SGI's expertise will be required most. Can Venter create, using his demonstrated skills in genetic engineering, synthetic algae strains:

1. with high lipid content that
2. exhibit much higher productivities / yields, while
3. being immune to contamination from other elements, and
4. at the same time are tolerant of specific environments?

This is a trillion dollar question. I'd bet my entire wealth (sadly, not a lot) that this where Venter will put in most of his research resources.

My colleagues tell me that there's a good amount of understanding already existing about the genomes responsible for high lipid content and for providing immunity to contamination, which will make these aspects even more interesting to Venter.

The other aspect mentioned earlier – higher yields – could be another low-hanging fruit, with considerable research likely having taken place already on genomes responsible for growth rates.

Environment tolerance is an area familiar to genetic engineering professionals. Thus, expect quick progress to be made on this aspect. Here, the efforts will be to use GM to produce strains that can grow well under existing temperatures, pH and other medium factors such as salinity.

An interesting idea came from my colleague Mathumitha Balu, who pointed out that GM could also enable mixotropic cultivation, where multiple algae strains are cultivated in the same medium. Mixotropic cultivation could be preferred in some cases because it is the natural form of algae growth in those environments – this is true especially where algae are grown in open systems. One of the hurdles to mixotropic cultivation currently is that the chemical compounds released by one strain could be "toxic" to the other strain/s. If, through GM, one were able to prevent the "toxin" being released, the possibility of mixotropic cultivation becomes enhanced to that extent.

In sum, expect a good amount of of those $600 million pumped in by Exxon Mobil to go into algae strain research using genetic tools.

Lowering the cost of cultivation

To a certain extent, the challenge of high cultivation cost can be taken care of if an optimal strain is chosen with high productivities, oil content, high environmental tolerance and resistance to contamination. Thus, GM plays a role here.

There's another interesting aspect to consider – water. The amount of water required for algae cultivation is large. (Still, I see few people really factoring in the criticality of water, or attaching a cost to it in their calculations.) Thankfully, one way by which water can indeed be obtained free of cost is by using sea water. But you need specific strains of algae (such as those belonging to the Nannochloropsis species) for marine water, and these strains might not necessarily have all the desired characteristics. What if highly desirable strains were genetically modified so they could thrive in marine water? Success in such an effort will go a long way in lowering the cost of cultivation, while at the same making large-scale algae cultivation that much more feasible.

I however feel that there is a limit upto which biotechnology plays a role in influencing cultivation costs. Cultivation costs also to a significant extent depend on the cost of construction and maintenance of open ponds or photobioreactors, cost of equipments used for mixing and aeration etc. These are areas where engineering technology, rather than biotechnology, plays an important role.

Inference: Both engineering technology and genetic technology will be needed to lower the costs of cultivation.

High cost of harvesting

In the case of microalgae cultivation, harvesting can add to the costs significantly, contributing as much as 20 percent of the total cost of production. Even if one were to use fairly simple belt filters for harvesting, the costs can be as high as $75-100 per T of dry algal biomass.

On the face of it, harvesting really looks like an engineering problem where Exxon's skills will be more in need than SGI's genetic engineering skills. But there are creative concepts that could indeed bring genetic engineering skills into play.

Let's consider autoflocculation, a phenomenon in which algae clump together on their own to form a thick mass that can harvested easily, at much lower costs than otherwise. Even today, in nature, there are some algae that autoflocculate; however, these strains have little or no oil. What if genetic engineering methods are used to make high oil bearing algae to get the characteristic of autoflocculation? You get the idea…

However, expect biotechnology / genetic engineering to play only a minor role here.

High costs of drying

Drying appears to be such an innocent little thing, you wouldn't think its cost could amount to anything. You couldn't be more wrong. Based on the calculations done by the Oilgae team, drying alone could cost upwards of $2 per gallon of algae biodiesel, if we use the traditionally used dryers such as spray dryers. It is likely that a more efficient drying system specifically adapted for making dry biomass for fuel could cost less, but even if one were to assume an 80 percent reduction, to $0.5 per gallon, the cost is still high!

Trust me, reducing the costs of drying could be a far more critical concern than what we all have assumed so far. Can genetic engineering play any role here?

Well, this was a toughie. I had almost given up trying to find a way where GM could play a role in more efficient drying when my colleague Parkavi Kumar pointed out to what OriginOil claims to be doing – bypassing the entire drying step (or for that matter, harvesting step), by extracting oil from the algae without killing the cells (http://www.originoil.com/technology/live-extraction.html). Wouldn't it be possible for genetic engineering to evolve algae that have cells less tough than normal so that such a "live extraction" becomes easier? Why not, I exclaimed, why not indeed – after all, we are talking about theoretical possibilities here!

So what do I think? Methinks that GM is unlikely to play any role here, unless we wish to get a bit fanciful.

Summary

Based on the research and brainstorming the Oilgae team did over the past one week on the impact of genetic engineering and Craig Venter's recent breakthrough in "creating synthetic life", it appears that Venter, with his expertise (and with a dose of imagination) could indeed influence algae fuel production by being able to address critical challenges along many points in the production value chain. The influence of genetic engineering will be highest in strain selection and cultivation, but they could play a role in making cost-effective harvesting and drying a reality as well.

A related question is, of course, how quickly could Venter's expertise overcome the challenges. Perhaps we will have some indications from him soon. Some statements jointly made by him and Exxon Mobil last year (at the time of their partnership agreement) suggested that it could take upwards of five years. Let's hope his latest achievement shortens this.