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The Development of Process Indicators for Science Communication using Social Marketing and Innovation Theory

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List of Acronyms

CALMAST	Centre for the Advancement of Learning of Maths, Science and Technology
DE	Department of Education
DEE	Department of Enterprise and Employment
DES	Department of Education and Science
DES*	Department of Education and Skills
DETE	Department of Enterprise, Trade and Employment
DJEI	Department of Jobs, Enterprise and Innovation
DSE	Discover Science and Engineering
Ed.	Educational
EFA	Exploratory Factor Analysis
FDI	Foreign Direct Investment
HEA	Higher Education Authority
ICSTI	Irish Council for Science, Technology and Innovation
IDA	Industrial Development Authority
IP	Intellectual Property
IRCHSS	Irish Research Council for Humanities and the Social Science
IRCSET	Irish Council for Science, Engineering and Technology
KMO	Kaiser-Meyer-Olkin
NBST	National Board for Science and Technology
NDP	National Development Plan
OECD	Organisation for Economic Co-operation and Development
P	Participant
PRTLI	Programme for Research in Third Level Institutions
Qual	Qualitative
QUAN	Quantitative
R	Researcher
RO	Research Objective
ROI	Republic of Ireland
ROSE	Relevance of Science Education
RQ	Research Question

S&T	Science and Technology
SET	Social Ecology Theory
SFI	Science Foundation Ireland
SSTI	Strategy for Science, Technology and Innovation
STEM	Science, Technology, Engineering and Mathematics
STI	Science, Technology and Innovation
STIAC	Science, Technology and Innovation Advisory Council
VNA	Value Network Analysis

Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Doctor of Philosophy, is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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Signature of Candidate:

Date:

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Abstract

Science surrounds our daily lives and is an integral component to the development of sustainable communities and societies. Science also contributes to the competitiveness and advancement of economies through their governing policies. Science policy formulation, both historically and presently, has been guided by authoritarian processes of oversimplification emphasising science and science communication as a product.

Science communication is currently shifting from the transitory periods of information and deliberation to public participation, which mobilises science as a process. Social marketing and innovation theory assist science communication in overcoming its product orientation by developing more integrated, open and proactive understandings of participatory processes for science-in-society. The foremost contribution of this study is the development of process indicators based upon the integration of science communication with social marketing and innovation theory to measure the non-linear and multi-dimensional nature of science.

This research contributes to a deeper and more integrative understanding of information, deliberation and participation in science communication. Social marketing and innovation theory emphasise the economic and social value to participation, as multiple levels of society co-integrate their ideas, knowledge and skill sets to co-produce and co-create participative processes for science communication. More specifically, this research allows policy makers and practitioners to focus on *what* is being co-ordinated; the system parts, their unique attributes and *how* participation is occurring between science communicators. Process indicators demonstrate that complex societal problems require multi-level and multi-directional participatory processes between diverse and conflicting stakeholder groups. Boundaries must be spanned and shared value networks co-created for experiential solutions to facilitate not just social good, but far-reaching societal change for science communication.

Publications and Peer Reviewed Conference Proceedings

Peer Reviewed Publications

Domegan, C., Collins, K., Stead, M., McHugh, P. and Hughes, T. (Under Review) Value co-creation in social marketing: functional or fanciful? *Journal of Social Marketing*, 3(3).

Edvardsson, B., Kleinaltenkamp, M., McHugh, P., Tronvoll, B., Watts, J. and Windahl, C. (Forthcoming 2013) Institutional Logic Matters – Coordinating Resource Integration. *Marketing Theory*.

McHugh, P. and Domegan, C. (Forthcoming 2013) From reductionism to holism: how social marketing captures the bigger picture through system indicators' In Kubacki, K. and Rundle-Thiele, S. (Eds) *Contemporary Issues in Social Marketing*. UK, Cambridge Scholars Publishing Ltd.

McHugh, P. (2012) *Social Marketing to Protect the Environment: What Works*, by Doug McKenzie-Mohr, Nancy R. Lee, P. Wesley Schultz and Philip Kotler. Reviewed in: *The Irish Journal of Management*, 31(2), 133-136.

McHugh, P. and Domegan, C. (2010) 'Systematic reviews: their emerging role in the co-creation of social marketing value'. Regulation and Best Practices in Public and Nonprofit Marketing, Bucharest, International Congress.

Peer Reviewed Conference Presentations

Domegan, C., Devaney, M., Hogan, M. and McHugh, P. (Forthcoming 2013) 'Transformative Stakeholders: Moving from a Marine, Fisheries and Coastal Management Centric View to a Societal Systems Change Perspective'. New Challenges and Solutions to Social Change; World Social Marketing Conference, Toronto, Canada.

Devaney, M., Domegan, C., Hogan, M. and McHugh, P. (2013) 'Transformative Marine Stakeholders: Moving from a Marine, Fisheries and Coastal Management Centric View to a Societal Marine Ecosystem Perspective'. Environment: From Ecosystem Functioning to Human Health'. Environ: The 23rd Irish Environmental Researcher's Colloquium; National University of Ireland Galway, Galway, Ireland.

McHugh, P. and Domegan, C. (2012) 'From Mechanistic Market Structures to Holistic Marketing Systems: How Social Marketing Captures the Bigger Picture through System Indicators'. Forum on Markets and Marketing 2012 (FMM12); University of Auckland Business School, Auckland, New Zealand.

McHugh, P. and Domegan, C. (2012) ‘Shifting the Systems Dynamic from the Stone to the Bird: A Social Marketing Approach to the Co-Creation of Science Policy’. Using Social Marketing to Deliver Effective and Efficient Citizen Focused Social Programmes; European Social Marketing Conference, Lisbon, Portugal.

McHugh, P. and Domegan, C. (2012) ‘From Reductionism to Holism: How Social Marketing Captures the Bigger Picture through System Indicators’. Using Social Marketing to Deliver Effective and Efficient Citizen Focused Social Programmes; European Social Marketing Conference, Lisbon, Portugal.

McHugh, P. and Domegan, C. (2012) ‘From Mechanistic Structures to Holistic Systems: How Social Marketing Captures the Bigger Picture through System Indicators’. Delve Deeper; International Social Marketing Conference, Brisbane, Queensland, Australia.

McHugh, P. and Domegan, C. (2012) ‘The Stone versus The Bird: Social Marketing’s Role in Co-Creating Science Policy’. Delve Deeper; International Social Marketing Conference, Brisbane, Queensland, Australia.

McHugh, P. and Domegan, C. (2012) ‘From Mechanistic Snapshots to Holistic Portraits: Capturing the Bigger Picture through Social Marketing Indicators’. Social Marketing and Socially Responsible Management: Taking Responsibility; ISM-Open University Conference, Milton Keynes, UK.

McHugh, P. and Domegan, C. (2011) ‘From Closed Models of Authoritive Governance to Open Systems of Collaborative Engagement: Progressing Science Policy’ Building Capacity for Scientific Research, Innovation and Outcomes; Atlanta Conference on Science and Innovation Policy, Atlanta, Georgia, USA.

McHugh, P. and Domegan, C. (2011) ‘From Autocratic Governance to Collaborative Empowerment: A Total Market Approach to the Private, Public and Third Sector Trinity’. 8th Workshop on the Challenges of Managing the Third Sector; European Institute of Advanced Management Studies (EIASM), National University of Ireland Galway, Galway, Ireland.

McHugh, P. and Domegan, C. (2011) ‘From Closed Policy Structures to Open Systems of Collaborative Engagement: A Social Marketing Approach to Progressing Science Policy’. Inspiring Open Innovation Team; The Open Innovation Symposium, UCD Michael Smurfit Graduate Business School, Dublin, Ireland.

McHugh, P. and Domegan, C. (2011) ‘From Authoritive to Collaborative Engagement: A Social Marketing Approach to Progressing Science Policy’. Addressing the Major Behavioural Challenges of Our Time: Engage, Empower, Inspire; The 2nd World Non-Profit and Social Marketing Conference, Dublin, Ireland.

McHugh, P. and Domegan, C. (2011) ‘Systematic Reviews: Their Emerging Social Marketing Role in Co-Creating Collaborative Change’. Addressing the Major Behavioural Challenges of Our Time: Engage, Empower, Inspire; The 2nd World Non-Profit and Social Marketing Conference, Dublin, Ireland.

McHugh, P. and Domegan, C. (2010) ‘From Authoritive Governance to Collaborative Empowerment: A Social Marketing Approach to the Co-Creation of Science Policy’. Social Marketing and Socially Responsible Management: Changing Times, New Challenges; ISM-Open University Conference, Milton Keynes, UK.

McHugh, P. and Domegan, C. (2010) ‘From Authoritive to Collaborative Knowledge Co-Creation: Progressing from Science ‘and’ Society to Science ‘in’ Society’. The Social Sciences in an Age of Uncertainty: Knowledge, Innovation, Society and Space; Irish Social Sciences Platform Annual Conference, University of Limerick, Limerick, Ireland.

McHugh, P. and Domegan, C. (2010) ‘Systematic Reviews: Their Emerging Role in Co-Creating Strategic Links for Innovation’. Building Collaborative Networks for Innovation; InterTradeIreland Innovation Conference, Dublin, Ireland.

McHugh, P. and Domegan, C. (2010) ‘Systematic Reviews: Their Emerging Role in the Co-Creation of Strategic Social Marketing Networks’. Renewing the Management Research Mandate; Irish Academy of Management Conference, Cork Institute of Technology, Cork, Ireland.

McHugh, P. and Domegan, C. (2010) ‘Systematic Reviews: Their Emerging Role in the Co-Creation of Social Marketing Value’. Regulation and Best Practices in Public and Nonprofit Marketing; 9th International Congress of the International Association on Public and Nonprofit Marketing, Bucharest, Romania.

McHugh, P. and Domegan, C. (2010) ‘Systematic Reviews: Their Emerging Role in the Co-Creation of Strategic Social Marketing Value’. Making it Happen: Changing Behaviours and Changing Policy; 2nd Annual Social Marketing Conference, National University of Ireland Galway, Galway, Ireland.

McHugh, P. and Domegan, C. (2009) ‘Systematic Reviews: Their Emerging Role in Connecting Theory and Policy’. Social Science Research and Policy Making: Bridging the Divide; Irish Social Science Platform Annual Conference, National University of Ireland Galway, Galway, Ireland.

Domegan, C., Cunningham, J. and McHugh, P. (2009) ‘The Knowledge Society, Management 2.0 Models and Social Innovation’. Changing Lives for Good: First Annual Social Marketing Conference; National University of Ireland Galway, Galway, Ireland.

Chapter One: Introduction

1.0 Introduction

Science is an everyday phenomenon. It occurs everywhere and to every living organism despite our unconscious awareness of its existence. Science has the capacity to shape our external environments, through the advancement of the physical and biological sciences. Weigold (2001) establishes that the spectrum of science reaches far beyond the physical and biological sciences; it incorporates medicine, engineering, environmental science, technology and the social and behavioural sciences.

Science is important to the development, productivity and growth of an economy (Forfas, 2012). In Ireland, the State science budget in the period 2002-2011 amounted to €23 billion (Hennigan, 2012). This total includes the cost of producing and training third level science, technology, engineering and mathematics graduates. In 2011, the total estimated expenditure for science and technology reached €2.369 billion (Forfas, 2012). It is anticipated that these deep investments in science will see Ireland by 2020, as the best country in the world for scientific research excellence and impact (Hennigan, 2012).

Science serves a plurality of roles at varying levels of society, such as individual, interpersonal, institutional, community, societal and public policy (McLeroy et al., 1988 and Morgan and Hunt, 1994). A fundamental, yet challenging role of science with society is the communication of scientific facts, issues and knowledge (Guedes-Vaz and Guimaraes-Pereira, 2006; Irwin, 2009; Jensen and Holliman, 2009). Traditionally, the communication of science embraces an information-transmission model where there is a clear and succinct separation between the science community and society (Van der Hove and Sharman, 2006; Leach, Yates and Scanlon, 2009; Tlili and Dawson, 2010). However, this separation:-

"faces new and unprecedented challenges where the science community and society can no longer ignore each other. They are now at a crossroads where they must continue together. And if science is a complex system and if society is a complex system, their interfaces will be a doubly complex system. And this is where we stand now – lost in a complexity that cannot be reduced to easily workable systems" (Guedes-Vaz and Guimaraes-Pereira, 2006, p.10).

The complex integration of science with society cannot be reduced to information-transmission models alone (Guedes-Vaz and Guimaraes-Pereira, 2006), and therefore, a movement towards a participatory egalitarianism for science communication has been popularised by Stirling (2006) and Van der Hove and Sharman (2006). Science communicators such as Gregory and Miller (1998) alongside Wilsdon and Willis (2004) and Stilgoe and Wilsdon (2009) have also conceptualised the need for a participatory approach to science communication.

The crux of science communication is to combine the conceptualisation of participatory processes in communication with its formal measurement. However, there is no consensus model of measurement to guide this understanding of participatory processes in science communication. The literature, until a consensus model of measurement is developed, continues to revisit the counter arguments between informing and mutual learning models of communication in science (Van der Hove and Sharman, 2006).

In Ireland, the context in which science communication has mobilised towards a participatory approach can be traced through a sixty year periodisation, reflecting science communication as a complex and multifaceted system (Guedes-Vaz and Guimaraes-Pereira, 2006).

1.1 A Structural Periodisation of Science Communication in Ireland

The structural composition of science communication has been greatly influenced by two dominant interfaces; the informing model of communication and the mutual learning model of communication (Van der Hove and Sharman, 2006). Science communication is an evolving and progressive area which cannot be contained to one presiding model of communication (Gregory and Miller, 1998; Leach, Yates and Scanlon, 2009) Instead, Van der Hove and Sharman (2006) articulate that science communication moves through revolutions where informing and mutual learning can co-exist through a participatory approach to science communication.

The periodisation of science communication in Ireland, as illustrated in Figure 1.1, succinctly captures how complex the system of science communication is, with its structural composition including multiple stakeholders, groups and institutions (Bergek et al., 2008) from policy, practice and public levels in science communication.

The configuration of science communication structures has evolved in tandem with the communicational interfaces between the science community and society. These interfaces can be best captured through three dominant stages of development in science communication; namely the *Period of Discovery (1950 – 1970's)*, *Period of Conceptualisation (1980 – 1990's)* and most recently the *Period of Enlightenment (2000 – Present).*

Figure 1.1 Historical Timeline of Science Communication in Ireland

Structures Governing Science Communication

1950	IDA
1969	HEA National Science Council
1977	NBST
1987	Eolas Office of S &T STIAC
1992	Single European Market
1993	DEE
1994	Forbairt Forfas Enterprise Ireland
1997	DE to DES DEE to DETE National Competitiveness Council ICSTI
2000	SFI STEPS to Engineering IRCSET Taskforce on the Physical Sciences
2001	IRCHSS
2003	CALMAST DSE
2004	Office of the Chief Scientific Advisor Cabinet Committee on S, T & I
2005	Advisory Science Council
2010	DES to DES*
2011	DETE to DJEI
2012	Closure of the Office of the Chief Scientific Advisor Appointment of SFI Director General

Influential Acts, Reports and Strategies for Science Communication

1974	National Science Council Report
1982	Telesis Report
1986	Single European Act
1987	S & T Act
1992	Cullinton Report
1993	Industrial Development Act
1994	NDP (1994-1999)
1995	STIAC Report
1996	White Paper Report
1998	Education Act
1999	PRTLI Initiative Technology Foresight Initiative
2000	NDP (2000-2006) Lisbon Strategy
2001	Science & Society Action Plan ICSTI Commission
2002	Taskforce on the Physical Sciences
2006	SSTI (2006-2013)
2007	ROSE Report NDP (2007–2013)
2009	STI – Delivering the Smart Economy Report
2011	SSTI Indicators Report
2012	The Science Budget 2010 -2011
2014	Horizon 2020

1.1.1 Period of Discovery: 1950 -1970's

The period of discovery represents the embryonic and formative years for science communication. During this era, the Industrial Development Agency (IDA) became the most influential structure for science and its communication, as seen in Figure 1.1.1.

The IDA had two key responsibilities during the period of discovery; the first involved securing industrial investment from national and international enterprises. The second responsibility of the IDA was a direct output of industrial investment whereby, the agency had to create and maintain a well educated workforce in the areas of science, technology and engineering. Together, the IDA and the Higher Education Authority (HEA) emphasised the need for a scientifically literature population to sustain current Foreign Direct Investment (FDI) and to further attract international investment and the relocation of multinational companies to Ireland.

Throughout this period, policy makers alongside the science community identified a shortfall of expertise in science and its related disciplines. Governing structures in science communication perceived education to be the ultimate solution in creating a scientifically literate population. Bradshaw and Borchers (2000) critiqued these historical approaches to science policy coordination as being indoctrinated by an authoritarian process of oversimplification. Fortifying this perspective, Swyngedouw (2000) alongside McGuire and Olson (1996) recognised that governing structures were operating under a regime of autocratic governance, creating oversimplified solutions to very complex policy and societal issues.

Autocracy during the discovery era for science communication adopted the information-transmission style to communication where governing structures knew best (Chapman, 2004). Policy makers and the science community "at the top of the knowledge heap, communicated valuably with each other through technical media and occasionally aimed a few scraps at the humble and passively recipient public down below" (Gregory and Miller, 1998, p.86). A communication hierarchy between policy makers, the science community and society became apparent during the discovery era to lift the "scientifically illiterate public out of its illiteracy" (Tlili and

Dawson, 2010, p.438). The communication hierarchy created a science-policy gap between policy makers and the science community as science precedes policy and a policy-public gap where the public were perceived as scientifically illiterate. The debate surrounding illiteracy in science communication continues as authors such as Sturgis and Allum (2004); Wilsdon and Willis (2004); Bauer, Allum and Miller (2007); Kim (2007); Trench (2008); Bauer (2009); and Davies et al., (2009) argue that increased knowledge through education does not automatically transfer into the publics increased awareness of, support for, and participation in science.

Figure 1.1.1 A Period of Discovery for Science Communication

Structures Governing Science Communication		**Influential Acts, Reports and Strategies for Science Communication**	
1950	IDA		
1969	HEA National Science Council		
		1974	National Science Council Report
1977	NBST		

Issue: Public’s Knowledge of Science
Focus: Create a Scientifically Literate Public
Model of Communication: Informing; Information-Transmission

1.1.2 Period of Conceptualisation: 1980 – 1990’s

The communication hierarchy between policy makers, the science community and society became more pronounced during the conceptualisation period. Policy makers, regulators and key decision makers took decisive action to tackle two persistent policy challenges of “embedding multinational companies in the economy and developing an internationally competitive indigenous sector” (Hilliard and Green, 2004, p.6). Science and its communication became foundational to securing further foreign direct investment and subsequent multinational relocations as well as strengthening the indigenous sector.

Throughout the 1980's, Ireland made significant progress in advancing its dedication to science and its communication. In 1987, the Irish government identified the need to establish its first movement towards science policy with the legislation of the Science and Technology Act. The government also established two structures to assist in the formulation and adoption of science promotion and development. The two groups were the Office of Science and Technology and the Science, Technology and Innovation Advisory Council (STIAC).

During the 1990's, several highly regarded reports were published for science communication such as the Cullinton Report, STIAC Report and the White Paper Report, as illustrated in Figure 1.1.2. One of the most influential reports; the White Paper, recognises the significance of science to society and the vital role it upholds in communities, workplaces and governments, while emphasising the need for greater scientific awareness and raising its levels of appreciation. The report recommends an open forum between science and the public to discuss the importance of science to society and the economy. Additionally, the White Paper proposes new governance structures for science communication which encourage open dialogue and collaborative relationships.

The conceptualisation period for science communication slowly shifts from informing models of communication towards the embodiment of learning and the understanding of science (Van der Hove and Sharman, 2006). Inzelt (2008) proposes that a successful science communication system needs to move away from a centralised top-down model and pay much more attention to dialogue. In this era, deliberative democracies emerge as science policy makers and the science community engage in bidirectional processes of communication with society (Burns, O'Connor and Stocklmayer, 2003; Jackson, Barbagallo and Haste, 2005; Schaefer, 2009 and Davies et al., 2009). And although the era of conceptualisation increased the flow of knowledge to the public, it inadvertently affected the publics' attitude to science (Bucchi, 2008; Trench, 2008 and Bauer, 2009). Bauer (2009) suggests that the focus for the conceptualisation period has moved away from knowledge to that of attitudes where one is not literate or illiterate, but more or less knowledgeable.

Figure 1.1.2 A Period of Conceptualisation for Science Communication

	Structures Governing Science Communication		**Influential Acts, Reports and Strategies for Science Communication**
		1982	Telesis Report
		1986	Single European Act
1987	Eolas	1987	S & T Act
	Office of S & T		
	STIAC		
1992	Single European Market	1992	Cullinton Report
1993	DEE	1993	Industrial Development Act
1994	Forbairt	1994	NDP (1994-1999)
	Forfas		
	Enterprise Ireland	1995	STIAC Report
		1996	White Paper Report
1997	DE to DES		
	DEE to DETE	1998	Education Act
	National Competitiveness Council		
	ICSTI	1999	PRTLI Initiative
			Technology Foresight Initiative

Issue: Public’s Attitude to Science
Focus: Increase the Public’s Understanding of Science
Model of Communication: Dialogue; Deliberative Democracy

1.1.3 Period of Enlightenment: 2000 – Present

Until this period, two issues in science communication prevailed. The first issue emerged during the period of discovery where a knowledge deficit was attributed to an insufficiently literate public (Bauer, Allum and Miller, 2007). The second issue brought to prominence in the period of conceptualisation was the publics’ attitude to science (Bucchi, 2008; Trench, 2008; Bauer, 2009).

In the enlightenment period, science, its communication and promotion alongside the development of research come to the fore. Policy makers and the science community acknowledge that “a two-way dialogue between science and society is required where each listens as much as talks” (Goncalves, 2006, p.178). As science communication moves upstream, structures such as Science Foundation Ireland

(SFI), STEPS to Engineering and Discover Science and Engineering are formed which emphasise public engagement with science and public participation in science. Science communication throughout the enlightenment period advances exponentially, as seen in Figure 1.1.3, with the pronounced formation of key structures and an increase in the funding, drive and support for science development, science education, science research, science communication and science promotion.

Figure 1.1.3 A Period of Enlightenment for Science Communication

Structures Governing Science Communication

2000	SFI STEPS to Engineering IRCSET Taskforce on the Physical Sciences
2001	IRCHSS
2003	CALMAST DSE
2004	Office of the Chief Scientific Advisor Cabinet Committee on S, T & I
2005	Advisory Science Council
2010	DES to DES*
2011	DETE to DJEI
2012	Closure of the Office of the Chief Scientific Advisor Appointment of SFI Director General

Influential Acts, Reports and Strategies for Science Communication

2000	NDP (2000-2006) Lisbon Strategy
2001	Science & Society Action Plan ICSTI Commission
2002	Taskforce on the Physical Sciences
2006	SSTI (2006-2013)
2007	ROSE Report NDP (2007–2013)
2009	STI – Delivering the Smart Economy Report
2011	SSTI Indicators Report
2012	The Science Budget 2010 -2011
2014	Horizon 2020

Issue: Public's Trust of Science
Focus: Public Participation in Science
Model of Communication: Mutual Learning; Participation

During the enlightenment period, a third issue emerges where the public are beginning to lose trust in the science community, in policy makers and subsequently, in science. Stirling (2006) proposes that enlightened science communication should be informed by, and should therefore incorporate more effective forms of symmetrical two-way deliberation, empowering inputs from a wider diversity of societal actors. Science communication at present, acknowledges that there is a need to engage in more meaningful and open dialogue processes where policy makers, the science community and society become part of the same communication system, and the communicators involved become part of a single community (Gregory and Miller, 1998). A single community for science communication shifts policy makers and the science community from informative and deliberative democracies to participative processes with mutual learning, transparency, openness and respect (Goncalves, 2006).

This sixty year periodisation illustrates how science has mobilised from a product to a process orientation. In parallel with the movement towards science as a process, the interfaces between science and policy integrate informing models of communication with reciprocated mutual learning models of communication. Processes in science communication emphasise the diverse totality of actors, discourse, structures, and processes implicated in guiding and shaping social good and participative change for science communication (Stirling, 2008). The integration of informative, deliberative and participative models of communication in science acknowledges the need to move upstream (Wilsdon and Willis, 2004). However, Wilsdon, Wynne and Stilgoe (2005) articulate that science policy makers and practitioners alike, are moving upstream without a paddle given the lack of formal advancement of participation and participatory processes in science communication.

The *Period of Discovery (1950 – 1970's), Period of Conceptualisation (1980 – 1990's)* and most recently the *Period of Enlightenment (2000 – Present)* have borne with them certain issues; focus paradigms and models of communication which are emphasised in the communication movement from information and deliberation to participation in science communication.

1.2 From Information and Deliberation to Participation in Science Communication

1.2.1 Information-Transmission in Science Communication

Science communication is a discipline which has gained significant recognition in both practice and research (Miller, 2001; Burns, O'Connor and Stocklmayer, 2003; Davies, 2008). Scientists in addition to their everyday activities are now charged with the role of communicating their scientific discoveries and knowledge with the public (Gregory and Miller, 1998). Borchelt (2001, p.196) suggests that there are three purposes to communication; "to inform citizens about scientific activities, products or conclusions that may be useful in improving the quality of life; to provide information for citizens to enable them to understand and perhaps participate in the formulation of public policy; and to provide descriptions and explanations of scientific work to enhance the level of scientific literacy in the recipient". Borchelt (2001) portrays communication as an informing process which epitomises simple linear models of communication (Gregory and Miller, 1998). Linear models of communication identify what the public ought to know, implying a one-way communication flow from the scientist to the general public, where the public is often seen as passive and sometimes poorly qualified receivers of knowledge (Burns, O'Connor and Stocklmayer, 2003; Martin-Sempere, Garzon-Garcia and Rey Rocha, 2008).

Borchelt (2001, p.196) continues to accentuate the informing perspective by delineating science communication as a process to "inform consumers, patients and citizens about scientific activities, products or conclusions of life generally or in regard to specific problems, issues or events". From this perspective, Borchelt (2001) is concerned with the communication of scientific truth, and the facts and the processes that support the communication of the truth to the publics who are affected by science. In essence, the inclusion of 'patients' by Borchelt (2001) recognises only those who are directly influenced by, consumers of, and users of science as opposed to those who are indirectly affected by its advancements.

Dornan (1990) unlike Borchelt (2001) acknowledges the communication connection with individuals who are indirectly influenced by science. Dornan (1990) classifies science communication as:

> *"An avenue of access to assured findings, and science – in this dissemination of these findings – as the initial sources. The members of the laity are understood purely as recipients of this information. Journalists and public relations personnel are viewed as intermediaries through which the scientific findings filter. The task for science communication is to transmit as much information as possible with maximum fidelity" (Dornan, 1990, p.51).*

Dornan's (1990) early insight into science communication amalgamates those individuals who are directly and indirectly influenced by science into one homogenous group - the laity. Categorising members of society as the laity is controversial, as it creates a hierarchical divide between expert scientists and the general public who are understood purely as recipients of scientific information (Dornan, 1990). The controversy surrounding the categorisation of the public as laity continues to prevail throughout the science communication literature (Logan, 2001; Manzini, 2003; Sturgis and Allum, 2004, Jackson, Barbagallo and Haste, 2005; Kurath and Gisler, 2009; Schafer, 2009).

Manzini (2003) defends this categorisation, as the author identified that if science is simply seen as a body of knowledge, then the communication of that knowledge will be characterised as a transmission from scientists to the laypeople. United in their distinctions between science and the elusive public laity, Dornan (1990) as well as Borchelt (2001) and Manzini (2003) advocate information-transmission models of communication, which are based on mechanical sender-transmitter-receiver communication styles (Gregory and Miller, 1998; Leach, Yates and Scanlon, 2009). Information-transmission models emphasise linearity, where scientific information flows from the privileged sender to the passive receiver (Leach, Yates and Scanlon, 2009). It conjures up ideas of "getting the message across, running public information campaigns, changing attitudes and raising awareness" (Sless and Shrensky, 2001, p.97). Furthermore, information-transmission encapsulates a one-dimensional perspective to science communication, where the scientific community emits information to be received by the public (Gregory and Miller, 1998).

1.2.2 Deliberative Democracies in Science Communication

Conflicting perspectives on the information-transmission model is expressed by Burns, O'Connor and Stocklmayer (2003, p.183) who suggest that science communication is "not simply encouraging scientists to talk about their work, nor is it an offshoot of the discipline of communications". Burns, O'Connor and Stocklmayer (2003) and Van der Sanden and Meijman (2008) instead, articulate that science communication is a two way deliberative process between the science community and the public. In contrast to the information-transmission model, these authors emphasise the communal sharing of information (Leach, Yates and Scanlon, 2009), where science communicators identify what society wants to know and finds ways to make this knowledge freely available and accessible (Borchelt, 2001).

Science communication embarks upon a dialogic turn (Davies, 2009; Zorn et al., 2012) as it is no longer seen as a "vehicle to increase acceptance amongst the public by simply transporting or translating science for the audience" (Schafer, 2009, p.476). Instead, dialogue in science communication is a collaborative, mutually constructive, and reflective conversational process in which participants actively examine and reconstruct relationships with others (Bokeno and Gantt, 2000; Zorn et al., 2012). The public are now viewed as contributors instead of the laity and science communication processes are shared and multi-directional (Logan, 2001).

The multi-dimensional view to science communication highlights a deliberative democracy where society learns about science through contribution (Tlili and Dawson, 2010). This contributory approach is effectively captured by Davison et al. (2008, p.4) who emphasise engagement in science communication as engaging diverse audiences can "increase public awareness of, support for, and participation in science, and influence school subject, degree and career choices". Engagement includes multiple publics, multiple purposes to science communication and also multiple outcomes relating to educational and societal progress.

The interchangeable perspectives on science communication thus far reflect the evolving nature, complexity and the multiple audiences associated with the science communication environment. Science communication has evolved from the dominant force of the information-transmission model to more contributory and dynamic methods such as deliberative democracies. Science communication is currently shifting from the transitory periods of information and deliberation to public participation (Chilvers, 2008; Lengwiler, 2008; Stirling, 2008; Chilvers, 2009; Pallett, 2012; Watermeyer, 2012).

1.2.3 Participation in Science Communication

Participation acknowledges mutual learning between multiple audiences of science communication where their participation or input can make a difference (Glicken, 1999). Participation is non-restrictive in nature as the process of communication is not limited to the scientist as sender and the public as receiver (Leach, Yates and Scanlon, 2009). To capture this comprehension of multiplicity, Burns, O'Connor and Stocklmayer (2003, p.191) identify that science communication may "involve science practitioners, mediators, and other members of the general public, either peer-to-peer or between groups"

Burns, O'Connor and Stocklmayer (2003) as well as Poliakoff and Webb (2007) and Fleming (2009) attribute five personal responses to participation; awareness, enjoyment, interest, opinion-formation and understanding in science communication which contributes to an informed society. Response multiplicity clarifies the purpose and characteristics of science communication as well as providing a benchmark for the evaluation of its effectiveness. Burns, O'Connor and Stocklmayer (2003) through their depiction of multiple communicators highlight how multiple audiences at multiple levels are involved in participatory science communication, moving beyond the limited capabilities of the information-transmission and deliberative democracy models of communication. Burns, O'Connor and Stocklmayer's (2003) participatory approach to science communication enhances shared meanings in science, encourages collaboration between the scientific community and society and enhances participatory learning (Zorn et al., 2012) across and between all levels in science communication.

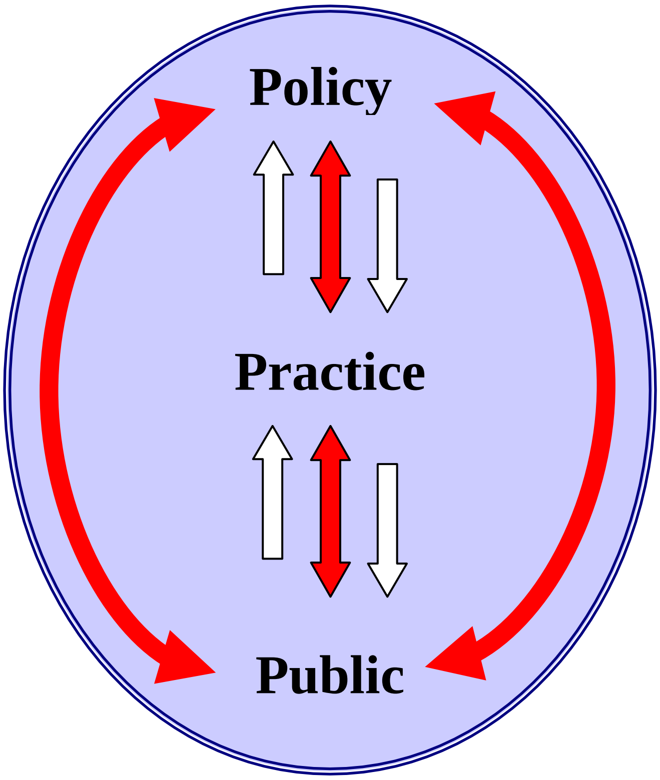
In summary, the informing and deliberative perspectives which have emanated in science communication are advancing towards participatory orientations in science.

1.3 Moving towards Participatory Systems in Science Communication

Over the last few decades, “in an attempt to claw back public trust, the institutions of science have begun to recognise the rationale for involving the public more intimately in their work” (Stilgoe and Wilsdon, 2009, p.19) As a result, the simple linear model of explaining science ‘to’ the public has been replaced by a complex, systemic, multi-directional and multi-level model of communicating science ‘with’ the public (Bora, 2005). In this way, the science community enables public debate to take place “upstream in the scientific and technological development process, and not downstream, where technologies are waiting to be exploited but may be held back by public scepticism brought about through poor public engagement and dialogue on issues of concern” (Stilgoe and Wilsdon, 2009, p.22).

Participatory systems in science communication open processes to a ‘new mood for dialogue’ (Gregory and Miller, 1998; Bucchi, 2008; Davies, 2008; Miller, Fahy and the ESConet Team, 2009), where communication occurs within and between the public, practice and policy levels in science communication, as evidenced in Figure 1.3. A participatory approach to science communication does not ignore informing models of communication, rather it integrates the model with dialogic turns (Davies, 2009; Zorn et al., 2012), mutual learning and more deliberative forms of communication.

Figure 1.3 Levels in Science Communication



Adapted from: Glicken (1999); Weigold (2001); and Lujan and Todt (2007)

Gregory and Miller (1998) reflect that webbed models of participation offer a more integrated approach to communication and interaction, without privileging any particular level, albeit policy, practice or the public. The literature in science communication acknowledges the need to further explore participatory approaches and processes (Wilsdon and Willis, 2004; Bauer, Allum and Miller, 2007; Lengwiler, 2008; Stirling, 2008; Chilvers, 2009; Yaneva, Rabesandratana and Greiner, 2009). However, Trench (2008) argues that the literature dedicates a disproportionate amount of time to delineating clear boundaries between literacy, understanding and public engagement in science communication. Alternatively, Trench (2008) suggests the focal models of deficit, dialogue and participation in science communication co-exist, as opposed to the sequential birth and death of each model throughout the periodisation eras.

Consequently, science communication has reached an impasse as there is no definitive framework to measure these co-existing processes of participation. The integration of science communication with social marketing and innovation theory provides a platform to deepen the analytical understanding of participatory processes in science communication. The rationale for using social marketing and innovation theory surrounds the depiction of multiplicity across levels and environment. Social marketing co-creates value *within* and *between* up, mid and downstream levels while innovation creates social and economic value exchanges *across* macro, meso and micro environments (Russell-Bennett, Previte and Zainuddin, 2009; Council on Competitiveness, 2005).

1.3.1 Science Communication and Social Marketing

Social marketing is a conceptual framework which applies marketing concepts and techniques to co-create value for individuals and society (Gordon et al., 2006; Lefebvre, 2012). Social marketing marries well with science communication as it recognises that the communication and promotion of science is much more than social propaganda (O' Shaughnessy, 1996). The ability to influence behaviour in science communication requires substantially more than education, persuasion and the exchange of ideas (Binney, Hall and Shaw, 2003). O'Shaughnessy (1996) suggests that science communication must move beyond didactic and transactional approaches of communicating 'to' the public, to a much preferred approach of participating 'with' the public (Mitsuishi, Kato and Nakamura, 2001; Davies, 2008).

Social marketing offers science communication a deeper understanding of its participatory processes through its core concepts; exchange and behavioural change. Exchange in social marketing is a complex process of interactions where actors accurately proportion the relinquishment of their self interested goals to the fulfilment of mutual interests and collective value (Henneberg, Mouzas and Naude, 2006). Exchange is central to science communication as multiple actors from multiple levels participate in social and relational exchanges, as opposed to the traditional top-down exchanges from policy and the science community (McKee and Wang, 2006).

Behavioural change theories in social marketing range from individual-based to population-based behaviour change (Serrat, 2010). Individual-based behaviour change incorporates downstream social marketing efforts where individuals are responsible for the modification of their behaviour (Goldberg, 1995). Lefebvre (2000) critiques social marketers for dedicating a disproportionate amount of attention to individual theories of change, realising the value of moving beyond individual-based behavioural change strategies to population and societal based change. Population-based behaviour change analyses change at the institutional and societal levels where the whole is greater than the sum of the parts (Langlois, 1983).

Social Ecology Theory (SET); a behavioural change theory advanced by Urie Bronfenbrenner acknowledges the connectedness of population-based behavioural change. SET has been chosen as the theoretical framework in this study to guide the understanding of a participatory approach in science communication. SET, as opposed to individual-based behaviour change models takes into account the publics' interaction with their physical environments and sociocultural surroundings (Sallis et al., 2006).

All too often, behavioural change strategies in science communication have attempted to understand the parts of a system through reductionistic methods, whereby the public's behaviour is reduced into rationally manageable components. Rather than positing that behaviour can be micro managed through the efforts of individuals at the policy level (Goldberg, 1995), SET analyses behavioural influences at multiple levels in a system (Dresler-Hawke and Veer, 2006; Sallis et al., 2006). SET offers valuable insights into science communication as the model integrates four broad levels of systems, namely micro-, meso-, exo- and macro-systems (Bronfenbrenner, 1979). Bronfenbrenner's (1979) micro, meso and macro system levels synergise well with the public, practice and policy levels in science communication. A social ecological approach to science communication analyses behaviour through top-down, bottom-up and interactive processes, capturing a total market approach to science communication (French, et al., 2010; Hoek and Jones, 2011; Lefebvre, 2011). Total market approaches to science communication "move us beyond a sole focus on the parts, referred to as reductionism, and instead shift our analysis to an alignment of interconnected parts linked together in a web of relationships" (Roberts, 2011, p.677). The avocation for interconnected coordination in Social Ecology Theory (SET) not only merges science communication with social marketing but it also underpins the strategic connection between science communication and innovation.

1.3.2 Science Communication and Innovation

Innovation, like science communication and social marketing is an interactive process which creates economic and social value (Council on Competitiveness, 2005; Lundvall, 2007). Value becomes an important output of the innovation process as Conroy (2007) articulates that innovation is about taking knowledge and rearranging it into a new context to make it more valuable. Innovation creates economic and social value through three interlinked levels; the macro environment, the meso environment and the micro environment. These iterative levels connect well with the policy, practice and public levels in science communication, as does up, mid and downstream thinking from social marketing.

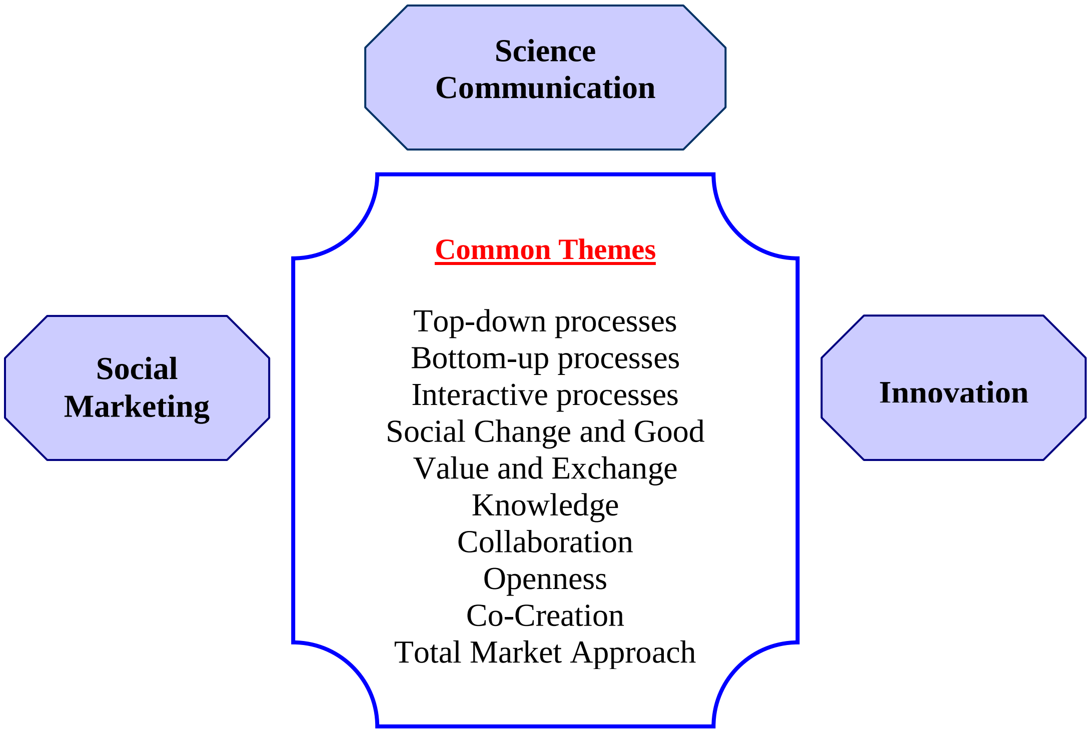
The interconnections between the macro policy level, meso practice level and the micro public level occur horizontally and vertically (Gulati, Nohria and Zaheer, 2000). Vertical coordination refers to managing top-down relationships between various levels of government and society. Horizontal coordination emphasises the emergence of collaborative relationships between macro, meso and micro individuals (Pelkonen, Teravainen and Waltari, 2008). The integration of horizontal and vertical coordination processes creates open systems of innovation (Chesbrough and Appleyard, 2007; Chesbrough, 2011; Lee, Olson and Trimi, 2012).

Open innovation and co-innovation (Lee, Olson and Trimi, 2012) emphasise a spiral exchange process for science communication, where tacit knowledge from the micro level is exchanged with explicit knowledge at the macro level (Nonaka, Toyama and Konno, 2000). Nonaka (1994) perceives the exchange process in innovation as non-linear with top-down, middle-up-down and bottom-up exchanges. The interactive mindset from innovation emphasises open engagement, where engagement need not mean a take-it-or-leave-it proposition (Chesbrough, 2011). Instead, policy, practice and public levels share their knowledge, ideas, skills and resources to collaboratively co-create economic and social value for science communication (Chesbrough, 2011).

The integration of science communication with social marketing and innovation theory creates several overlapping and common themes as illustrated in Figure 1.3.2. The rationale for using social marketing and innovation theory surrounds the depiction of multiplicity across levels and environments. In social marketing, French, et al. (2010), Hoek and Jones (2011) and Lefebvre (2011) capture a total market approach to social good where participation occurs through top-down, bottom-up and interactive processes. Total market approaches to participation facilitate exchange, interaction and communication between multiple stakeholders across and between up, mid and downstream levels in social marketing.

In innovation theory, Nonaka (1994) emphasises the non-linearity of innovation through top-down, middle-up-down and bottom-up exchanges between macro, meso and micro environments. Innovation purports a deeper understanding of participation as open and collaborate models of co-innovation facilitate shared value exchanges and mutual learning (Lee, Olson and Trimi, 2012). Collectively, social marketing and innovation theory emphasise the economic and social value to participation, as multiple levels of society co-integrate their ideas, knowledge and skill sets to co-produce and co-create participative change for science communication.

Figure 1.3.2 Common Theoretical Themes across Science Communication, Social Marketing and Innovation



1.3.3 Developing Process Indicators for Science Communication

The measurement of progress in science communication for policy makers and practitioners alike is through indicators. Godin (2001) stated that indicators became particularly salient to economics in the 1930s, through measures such as growth, employment, productivity and inflation. In line with economic indicators, social indicators were also developed but their prevalence did not emerge until the 1960s (Godin, 2001). Historically, science indicators have measured the progress towards a particular direction or away from a desired direction through informing indicators such as inputs and outputs. Science communication and its measurement are progressing beyond informative input-output metrics, emphasising the participatory nature to science through process indicators.

The co-integration and co-creation of multiplicity across exchange, communication and value between the up, mid and downstream levels of social marketing and the macro, meso and micro environments in innovation, provide an enhanced understanding of participatory processes for science communication and assist in the development of process indicators for science communication measurement. Process indicators for science communication measure changes in significant aspects of society (Godin, 2001). Process indicators acknowledge the non-linearity to science (Milbergs and Vonortas, 2004) and focus on "what is being coordinated; the system parts and their unique attributes and how coordination is occurring; the mechanisms that forge the integration of system parts and sustain them over time as a coherent whole" (Roberts, 2011, p.677). Process indicators examine the interrelationships and interconnections between elements, processes and outcomes in science communication (Vargo and Lusch, 2010). More specifically, process indicators in science communication measurement examine the elements that stipulate and shape the intricate interplays between macro, meso and micro phenomena, where macro-structures condition meso and micro-dynamics and vice versa new macro structures are shaped by meso and micro processes (Lundvall, 2007).

1.4 Formal Definitions for Study

The literature areas of science communication, social marketing, innovation and indicators are fraught with ambiguity as there are no single, consensus-based definitions employed in the four streams of literature. This section outlines the four key definitions chosen for science communication, social marketing, innovation and indicators in this study.

i) Science Communication:

As previously alluded to in section 1.1, the researcher has chosen the science communication definition of Burns, O'Connor and Stocklmayer (2003) for this study:

> *"Science communication may be defined as the use of appropriate skills, media, activities, and dialogue to produce awareness, enjoyment,*

interest, opinions and understanding of science. Science communication may involve science practitioners, mediators, and other members of the general public, either peer-to-peer or between groups" (Burns, O'Connor and Stocklmayer, 2003, p.191).

Burns, O'Connor and Stocklmayer's (2003) definition captures the premise of multiplicity in science communication. Science communication is an interactive process of informing, sharing and learning between multiple groups from multiple layers and levels in society (Tlili and Dawson, 2010). Burns, O'Connor and Stocklmayer's (2003) comprehensive definition enhances understanding and shared meanings in science, while encouraging collaboration across and between all levels in science communication.

ii) Social Marketing:

The concept of multiple audiences from science communication transcends social marketing as seen in Lefebvre's (2012) definition which incorporates individuals, organisations, networks, communities, businesses, markets and public policy.

"Social marketing develops and applies marketing concepts and techniques to create value for individuals and society. This is done through the integration of research, evidence-based practice and the use of social-behavioural theory together with the insights from individuals, influencers and stakeholders. These inputs and perspectives are used to design more effective, efficient, sustainable and equitable approaches to enhance social well-being. The approach is one that encompasses all the processes and outcomes that influence and are associated with change among: individuals, organisations, social networks and social norms, communities, businesses, markets, and public policy" (Lefebvre, 2012, p.120).

Lefebvre (2012) presents a social marketing definition which interconnects with science communication. Science communication as Godin and Gingras (2000) proffer is concerned with two scientific cultures: the individual and society. Both the individual and societal cultures are reflected in Lefebvre's (2012) interpretation of social marketing. Lefebvre (2012) also emphasises processes and outcomes that influence and shape change. Science communication is undergoing a transformational change from literacy and dialogue to public participation, and Lefebvre (2012) provides an insight into the participatory processes of science through the analysis of the multiple levels in society, from individual to policy, which is further supported in the workings of McLeroy et al. (1988) and Morgan and Hunt (1994).

iii) Innovation:

Science communication and the concept of multiplicity resurge in the definition of innovation presented by the Council on Competitiveness:

> *"Innovation is the intersection of invention and insight, leading to the creation of social and economic value" (Council on Competitiveness, 2005, p.8).*

Innovation emphasises multiple outcomes to the complex processes of invention and insight. The creation of value in innovation has a bidirectional influence on society and the economy. Economic and societal values embrace open and closed systems of innovation. Two complementary kinds of innovative openness co-exist: outside-in openness and inside-out openness (Chesbrough, 2011), both of which are relevant to science communication as policy and practice levels are shifting towards integrative participatory processes with the public.

iv) Indicators:

Indicators and science communication are inextricably linked as science discovers change in society and indicators measure those changes as evidenced in Godin's (2001) definition:

> *"Indicators are statistical time series that measure changes in significant aspects of society" (Godin, 2001, p.5).*

Godin's (2001) description of an indicator interrelates with science communication in three ways. Firstly, indicators are warnings about change (Godin, 2001). Secondly, indicators are statistics that must be recurrent; otherwise they would not meet the measurement of change (Godin, 2001). Science communication has evolved substantially since the 1950s, as the periodisation timeline illustrated in Figure 1.1. Indicators need to evolve in tandem with scientific and societal shifts as opposed to reacting to scientific inventions and insights (Council on Competitiveness, 2005). Thirdly, indicators usually appear as a collection of statistics rather than a lone statistic, as a lone statistic can rarely be a reliable indicator (Godin, 2001). Processes in science communication embody multiplicity and therefore multiple indicators are needed to measure the discipline accurately and effectively.

The definitions set out for this study by Godin (2001); Burns, O'Connor and Stocklmayer (2003); Council on Competitiveness (2005) and Lefebvre, (2012) emphasise similar characteristics which are summarised in Figure 1.4. These key characteristics are essential to the interpretation and understanding of participation in science as well the development of process indicators for science communication.

Figure 1.4 Key Characteristics of the Four Formal Study Definitions

KEY CHARACTERISTICS

- Dialogue
- Individuals and Society
- Creation of Value
- Social Well-Being
- Social Good
- Processes and Outcomes
- Change
- Invention and Insights

1.5 Research Question and Objectives

1.5.1 Primary Research Question

The primary research question of this study is how do process indicators contribute to the understanding of activities between science communicators in Ireland?

1.5.2 Secondary Research Objectives

The primary research question is supported by the following five secondary objectives:

Secondary Objective 1 specifically relates to the paradigms in science communication. Therefore, two parts to this objective have been devised; one theoretical and one empirical, as respectively outlined below:

(i) To delineate the different science communication paradigms.

(ii) To understand the roles of science communicators in the process of science communication.

Secondary Objective 2: To establish the key science-policy interfaces in science communication.

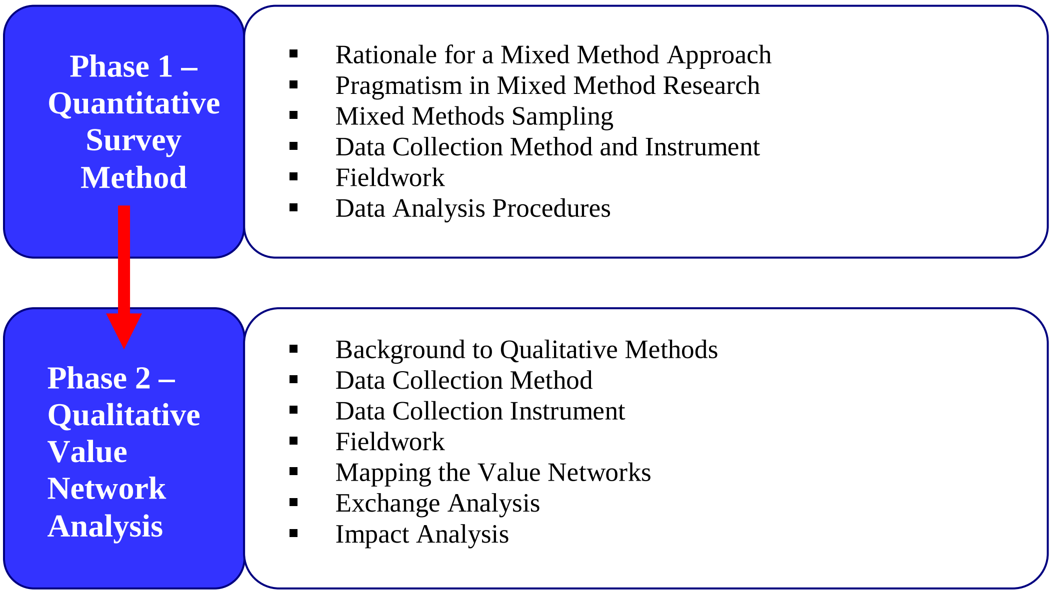
Secondary Objective 3: To determine how process activities differ, if at all, between science communicators with policy, practice and public orientations.

Secondary Objective 4: To analyse how value is created between science communicators.

1.6 Research Methods

Johnson and Gray (2010, p.70) identify that it "is important to dialogue not only with contemporary writers, but also with writers of past times, for if we ignore them, we might falsely believe we invented 'the debate' or the 'science wars' or the knowledge problem". This research adopts a two-phased methodology beginning with a quantitative survey method, which is sequentially followed by qualitative value network analysis, as illustrated in Figure 1.6.

Figure 1.6 Summary of Sequential Mixed Method Approach



Phases one and two embody a mixed method research approach, which are deductive in nature. Deductive approaches increase construct validity as deduction is concerned with theory testing and measurement as opposed to theory building and operationalisation (Bryman and Bell, 2007). This research through a sequential explanatory design measures four groups of process indicators for science communication. (Sandelowski, 2000; Creswell, 2003; 2009; Ivankova, Creswell and Stick, 2006; Gonzalez-Castro et al., 2010) The measurement of four process indicators in phases one and two of the mixed method research approach produces findings that provide a critical understanding of the research gaps identified in the science communication literature, as seen in Table 1.6.

Table 1.6 Overview of Research Gaps, Methods and Analysis

Research Gaps	Research Question (RQ) and Research Objectives (RO)	Method	Objectives	Analysis
Lack of understanding about how process indicators contribute to the understanding of participation in science communication	**RQ:** How do process indicators contribute to the understanding of activities between science communicators in Ireland?	Survey Method	To investigate how process indicators understand activities in science communication	▪ Exploratory Factor Analysis ▪ Multiple Regression
Lack of differentiation between science communication paradigms	**RO 1 (i):** To delineate the different science communication paradigms	Literature Review	To identify and critically analyse four science communication paradigms	N/A
Lack of understanding about the roles of science communicators	**RO 1 (ii):** To understand the roles of science communicators in the process of science communication	Survey Method & Value Network Analysis	To identify the roles of science communicators	▪ Frequency Counts ▪ Value Network Analysis
Lack of a consensus-based science-policy interface model in science communication	**RO 2:** To establish the key science-policy interfaces in science communication	Literature Review	To identify and critically analyse four science-policy interface models in science communication	N/A
Lack of understanding about how process activities differ between science communicators	**RO 3:** To determine how process indicators differ, if at all, between science communicators with policy, practice and public orientations	Survey Method	To understand which process indicators are relevant to science communicators with policy, practice and public orientations	▪ Correspondence Analysis
Lack of understanding about how value is created between science communicators	**RO 4:** To analyse how value is created between science communicators	Value Network Analysis	To understand how value is created and / or co-created in science communication	▪ Value Network Analysis

Phase one represents the dominant phase in the sequential explanatory design (Creswell, 2003) where an online survey was used as the quantitative data collection method. The rationale for using a quantitative online survey derives from the three streams of literature, as each of the authors of the adapted measurement scales in this study employed a survey methodology with a questionnaire as the research instrument. Dillman's (2007) tailored design method was employed to administer the online survey among science practitioners in the Republic of Ireland (ROI) and control for non-response error. The practice level in science communication represents the unit of analysis which is further stratified into three orientation levels - policy, practice and the public. Factor analysis alongside other categorical procedures is used to analyse the quantitative survey data. Factor analysis examines the whole set of interdependent relationships among variables, contributing to a deeper understanding of the process activities between science communicators (Malhotra, 2010).

Qualitative data is collected and analysed in the second phase to help explain, or elaborate on, the quantitative results obtained in phase one. The qualitative data and their analyses refine and explain those statistical results by exploring participants' views in more depth (Ivankova, Creswell and Stick, 2006). The qualitative dimension to the study examines specifically, how value is created between science communicators through the use of a mapping technique called Value Network Analysis (VNA). VNA in this study was used to determine the networking activities of science communicators. VNA goes beyond 'who' is involved in a network and effectively captures 'what' is exchanged and 'how' those exchanges take place in science communication. VNA is especially appropriate to the measurement of process indicators as value networks measure the overall pattern of exchange and value creation in a system, as well as analysing the best way to create, extend and leverage value between policy, practice and public levels in science communication (Allee, 2008).

1.7 Contributions to Knowledge

This research makes individual theoretical, methodological, policy and managerial contributions to identified knowledge deficits in science communication, social marketing, innovation and indicator theory and practice. Taken together, the foremost contribution of this study is the development of process indicators based upon the integration of science communication with social marketing and innovation theory.

1.7.1 Theoretical Contributions

The dominant stream of literature which guides this research is science communication. The literature in science communication has developed an over reliance on the paradigm discussions relating to science literacy, public understanding of science and science-and-society (Trench, 2008). Trench (2008) alongside Stirling (2006) cautions the discipline in treating each paradigm as sequential fragments. Instead, the literature needs to acknowledge the iterative and co-existent nature to deficits, dialogue and participation (Trench, 2008). This study integrates the three levels of policy, practice and the public with the four paradigms of science communication to contribute to, and deepen the understanding of participation and participatory processes in science communication.

The integration of science communication with social marketing and innovation theory is in itself a theoretical contribution to each of the bodies of literature. Social marketing and innovation theory craft a deeper understanding of participation, which moves the literature of science communication beyond the basic tenets of participation to a nuanced understanding of how participation between the policy, practice and public levels of science facilitates shared value, mutual learning and reciprocal exchange, interaction and communication. Social marketing and innovation assist science communication in overcoming its theoretical gaps by developing more integrated, open and proactive understandings of the participatory processes for science-in-society (Stirling, 2006).

The interdisciplinary integration of science communication with social marketing also advances the literature of social marketing as all too often the field is reluctant to move beyond individual-based behavioural change (Lefebvre, 2000). The incorporation of Social Ecology Theory (Bronfenbrenner, 1979) to the area of science communication in this study is a new and under-researched application of social marketing. This study expands the applications of social marketing beyond environmental and health applications to the upstream investigation of science policy and science communication. Theoretically, this study contributes to, and advances, the concept of a total market approach to social marketing that is currently in the embryonic stages of theoretical development. This study formally integrates Gronroos' (2004) relationship marketing concepts of communication and dialogue, interaction, value and value co-creation with a total market approach to social marketing. Currently, Marques (2008); Russell-Bennett, Previte and Zainuddin (2009) and Marques and Domegan (2011) advocate that co-creation in addition to interaction, dialogue, communication, and value creation are important constructs for effective participation and public empowerment within social marketing.

Furthermore, this study produces indicators which are highly relevant to the discipline of social marketing. Although the process indicator framework has been applied to the area of science communication, it is applicable to marketing systems, macro management, stakeholder analyses, value networks, and collaborative partnerships across health, the environment and conservational issues within social marketing.

Another theoretical contribution for social marketing lies in the amalgamation of the process indicators of trust, commitment, learning and reciprocity under the heading '*Intangibles*' in this study. Intangibles are a term synonymous with the services marketing literature yet the term has not been fully translated into the discipline of social marketing. The positioning of the term 'intangibles' with social marketing in this study, emphasises the applicability of service marketing constructs with social marketing, where at present the boundaries between the two disciplines are beginning to permeate through the work of Zainuddin, Russell-Bennett, and Previte in 2007 and Russell-Bennett, Previte and Zainuddin in 2009. This study also advances Hunt and Morgan's (1994) thinking on trust, as the authors advocate trust as an antecedent to relationship formation. The findings from this research identify reliability as the antecedent to trust which poses a new research avenue for social marketing.

The integration of science communication with innovation in this study also benefits innovation theory as Chesbrough’s (2011) concepts of closed and open innovation are extended beyond the micro level of the organisation to the macro level of society. Innovation theorists such as Peteraf (1993) and Barney (2001) emphasise the exchange of resources between micro-level organisations. This study advances the networking of networks exchange structure in innovation, as multiple organisations at multiple levels of society embrace spiral exchange processes of issues, ideas and knowledge in addition to tangible resources.

The foremost contribution of this study is the development of process indicators based upon the integration of science communication with social marketing and innovation theory. Milbergs and Vonortas (2004); Stone et al. (2008) and Rose et al. (2009) present the evolution of process indicators, which to date have not yielded empirical data or evidence in its applications to science, technology or innovation. This study through an interdisciplinary approach to science communication operationalises four process indicator categories; knowledge, intangibles, networks and system dynamics. Furthermore, this study deductively produces eleven construct definitions and eleven measurement scales for each of the process indicators. The measurement of these eleven process indicators not only advances the area of science communication but they also contribute to the enhanced understanding of a total market approach in social marketing and open system approaches in innovation.

1.7.2 Methodological Contributions

Methodologically, the science communication literature has tended to target the public. Studies from Lee, Scheufele and Lewenstein (2005); Pardo and Calvo (2006); Falk, Storksdieck and Dierking (2007); Kim (2007) and Powell and Kleinman (2008) examine public attitudes and perceptions towards science. Those studies which analyse the practice level of science communication do so in order to deepen the understanding of how the science community communicates with the public, where again the public becomes a focal target group (Mitsuishi, Kato and Nakamura, 2001; Poliakoff and Webb, 2007; Davies, 2008; Martin-Sempere, Garzon-Garcia and Rey-Rocha, 2008). This study contributes to science communication methodologies by emphasising the under-researched and under-explored but critical practice level. The practice level of science mediates between policy and public levels. This study advances the understanding of the practice level by examining the knowledge, networking, relational and structural processes of science communicators. Furthermore, this study for the first time graphically captures the networking of networks approach in science communication, by visualising how science communicators create, extend and co-create value at the practice level of science.

Traditional indicator research emphasises macro level activity in science. This research directly answers the call by Gault (2007) and Blankley (2009) to develop process indicators that produce meso level and micro level data. Meso level data arises from the understanding of science practitioners and micro level data is produced from the stratifications of the policy, practice and public level orientations of science communicators. Rose and McNiven (2007) maintain there is value in capturing indicators external to the macro realm. In this study, process indicators capture the coordination and exchange of resources at the meso and micro level of science communication, as well as highlighting how science communicators are connected to one other in the system of science.

This research employs Value Network Analysis (VNA) for the first time in science communication. VNA is traditionally applied to whole systems (Allee, 2008). In this study, VNA empirically examines networks of organisations as opposed to systems of organisations, extending the use and application of the VNA methodology in exchange and network theory. In addition, this study extends the concept of intangible deliverables in value network analysis to incorporate explicit and implicit values.

VNA in this study methodologically contributes to the literatures of science communication, social marketing and innovation, as frequently these literature streams use social network analysis as the main structural visualisation methodology. However, the empirical link between organisational level structures and firm level performance is under explored in a social network methodology. VNA in this study provides a fresh perspective for understanding value creating roles and relationships, and explains how to more effectively realise value through the utilisation of tangible and intangible assets for value creation (Allee, 2008).

Methodologically, VNA is highly relevant to the discipline of social marketing as value co-creation in social marketing focuses on the bi-directional and multi-directional interactions that occur between groups (Zainuddin, Russell-Bennett and Previte, 2007). Social marketing has yet to yield a network methodology that goes beyond the traditional approach of representing ‘who’ is involved in a network. Alternatively this study visualises bi-directional and multi-directional values, by capturing ‘what’ is exchanged in a network and ‘how’ those explicit and implicit values are exchanged for value co-creation to occur within social marketing.

1.7.3 Policy Contributions

A foremost contribution to science policy is the illustrative periodisation of science communication in Ireland (Figure 1.1), which comprehensively traces the evolution of historical policies and structures in science. Historical approaches to science communication policy, as illustrated in this periodisation timeline, are guided by authoritarian processes of oversimplification (Bradshaw and Borchers, 2000). As identified by Jones (2010) the process of science is now changing; and governments have a responsibility to move beyond top-down approaches to science policy formulation (Lefebvre, 2000), This research moves policy development and the science communication literature away from autocratic models of communication to the lateral integration of top-down and bottom-up participatory processes. The expanded understanding of participatory processes in science communication using social marketing and innovation theory co-creates meaningful and experiential solutions to complex policy and societal issues.

The development and measurement of process indicators in this study provides policy makers with an alternative model of measurement to the traditional and often restrictive input-output models in science (Godin, 2001). In the indicator literature, Gault (2007) and Blankley (2009) assert that the combination of macro level and micro level data for policy is more valuable to an economy and policy makers than macro level data alone. This study contributes to both science policy and indicator measurement as process indicators measure the activity of science communicators at the meso and micro levels of science which creates a more sophisticated measurement framework external to the macro science level or the individual micro level organisation.

This study illustrates how VNA is a valuable analytical technique for policy as it provides powerful insights into the health and sustainability of a policy system, whilst also providing a graphical representation of value networks in science communication. VNA captures the properties of the individual organisations in science communication as well as capturing a big picture model of the interactions, connections and linkages in the system. VNA effectively illustrates the processes by which science communicators form networks, exchange knowledge, build trust and enhance credibility. In this study, a policy contribution lies in the mapping of value networks which goes beyond 'who' is involved in science communication and effectively captures 'what' is exchanged in science communication and 'how' exchanges take place.

1.7.4 Managerial Contributions

The measurement of knowledge in an organisation is a multifaceted function of management. Process indicators from this study enable managers to gain a deeper understanding of how knowledge is generated within the boundaries of the firm. Innovation literature recognises that knowledge takes two forms; explicit and tacit knowledge (Seufert, vonKrogh and Bach, 1999; Choi and Lee, 2002; Katsamakas, 2007). The measurement of knowledge in this study provides an evidence base to managers on whether knowledge is generated within a firm through documents, manuals, and databases, or whether the knowledge is intrinsic to an individual. This information is valuable to a manager as it highlights the need to create or maintain the systematic storage and codification of organisational documentation and training manuals. Furthermore, the process indicators in this study also provide managers with information on knowledge transfer and exchange as well as network composition.

In this study, VNA provided powerful illustrative evidence of the exchanges which occur between an organisation and its networking partners. This type of information is important to management, as it comprehensively illustrates the connections, communicational linkages and exchanges of an organisation. VNA also identifies whether the exchanges are unidirectional, bi-directional or multi-directional. Value networks also distinguish between partners who are committed to long term relationships and partners who engage in unidirectional transactions for short term gain. Essentially, value networks demonstrate to managers the best way to create, extend and leverage value with other organisations.

VNA also provides a visualisation of value to management. The visual maps produced for participants in this study are currently being incorporated into the overarching communication strategies of participant organisations, which illustrate the networking partners of an organisation and the movement of knowledge between networks to management and head offices. VNA maps can also be integrated into end of year reports and presented to national funders as a justification for funds spent and the need for additional funding.

The use of VNA in conjunction with social marketing makes management more aware of the behaviours of their networking partners, acknowledging that behaviours do not occur in a vacuum. As a result of this study, management have become more conscious of the intangible constructs of trust, commitment and reciprocity throughout their daily routines and practices. Managers now reflect on the behaviour of their networking partners in terms of goodwill, reliability, credibility and trustworthiness, in order to decide between those whom the organisation connects with, disconnects from, or exchanges knowledge with in the future.

1.8 Scope and Limitations of the Study

There are a number of acknowledged limitations to this study. The principal limitation underlying this study is the operationalisation of the process indicators for science communication. The literature in science communication delimits itself to continual discussions regarding the deficit, dialogue and participation paradigms. Participatory processes are recognised as important, however, there has been little guidance in how to progress the analysis of participation and therefore, science communication has been moving upstream without a paddle (Wilsdon, Wynne and Stilgoe, 2005). Social marketing and innovation theory progress the theoretical insights and concepts of participation and assist in the conceptualisation of process indicators for science communication.

Another limitation concerns the empirical investigations within the field of science communication. Science communication has undertaken little to no empirical research in understanding the deficit and participation models beyond the public level. Studies have emphasised the need for science to better communicate with the public (Mitsuishi, Kato and Nakamura, 2001; Davies, 2008) as well as examining public perception and attitudes toward science (Lee, Scheufele and Lewenstein, 2005; Pardo and Calvo, 2006). The practice level of science communication apart from the exploratory work of Davison et al. (2008) remains under-researched and under-explored.

With regards to indicator research, the majority of authors supporting the need for enhanced metrics are writing in policy documents, industry circles and working papers. The theory within indicator research lags significantly behind the thinking in policy. Consequently, to better understand indicators and their current measurement models, this study amalgamates peer-reviewed journal articles with working papers and policy documents.

The employment of VNA in this research highlights inefficiencies of the approach when applied to the meso level of science communication. VNA traditionally analyses one purposeful activity among a network of organisations (Allee, 2009). VNA in this study was employed to understand the multiple activity processes between science communicator organisations, which extend beyond contractual relationships to the inclusion of non-contractual relationships. The analysis of non-contractual relationships in VNA is limited and has the potential to be more extensively investigated as part of further research.

The analysis of the online survey and value networks in this study adopted a cross sectional design to the mixed method research approach. The continued measurement and analysis of the participant organisations could augment the understanding of networks in science communication if the value network maps were revisited and extended into longitudinal research.

Finally, this study was confined to the ROI. The purpose of the research was to measure the process indicators in the ROI and not to generalise the results to science communication and populations outside of the ROI.

1.9 Structure of the Thesis

The structure of the entire thesis is presented in Figure 1.9. In Chapter Two, the existing science communication literature is analysed resulting in the identification of the theoretical gaps. The chapter identifies how theoretical gaps can be bridged through the enhanced need for measurable indicators in science communication.

Chapter Three introduces the literature areas of social marketing and innovation. The application of social marketing and innovation theory provide a holistic understanding of participation processes in science communication. Four key process indicators for science communication are developed to guide the sequential methodologies of the research.

Chapter Four outlines the pragmatic viewpoint of the study as well as justifying the use of a sequential mixed method research approach. The chapter also describes the quantitative and qualitative procedures undertaken to measure the process activities between science communicators in the ROI, as well as outlining the validity and reliability measures of the study.

Within Chapter Five, the key findings from the data reduction techniques including exploratory factor analysis and multiple correspondence analyses are discussed. In addition, the chapter also presents key findings from regression analyses.

Chapter Six presents the findings of seven value network maps and the analyses of these value network maps are discussed.

Figure 1.9 Thesis Outline

Chapter 1 **Introduction**	▪ From Information and Deliberation to Participation in Science Communication ▪ Formal Definitions for Study ▪ Research Question and Objectives ▪ Expected Contribution to Knowledge ▪ Scope and Limitations
Chapter 2 Science Communication and Its Measurement	▪ Levels in Science Communication ▪ Interfaces and Paradigms in Science Communication ▪ Theoretical Gaps in Science Communication ▪ Bridging the Gaps through Indicator Research ▪ The Need for Enhanced Indicators in Science Communication
Chapter 3 The Application of Social Marketing and Innovation to Science Communication	▪ Social Marketing: A Total Market Approach ▪ A Total Market Approach to Science Communication ▪ Innovation: A Multi-Dimensional View ▪ From Closed to Open Networks in Science Communication ▪ Developing Process Indicators for Science Communication
Chapter 4 Research Methodology	▪ Rationale for a Mixed Method Research Approach ▪ Pragmatism in Mixed Method Research ▪ Mixed Methods Sampling ▪ Data Collection Methods and Instruments ▪ Fieldwork ▪ Data Analysis Procedures ▪ Validity and Reliability
Chapter 5 Online Survey Findings and Analysis	▪ Respondent Profiles ▪ Exploratory Factor Analysis ▪ Correspondence Analysis ▪ Regression ▪ Thematic Analysis
Chapter 6 Value Network Findings and Analysis	▪ Mapping the Respondent's Networks ▪ Exchange Analysis ▪ Impact Analysis ▪ Value Creation Analysis ▪ Process Networks
Chapter 7 Conclusions and Recommendations for Future Research	▪ Conclusions and Implications ▪ Revisiting the Secondary Objectives ▪ Conclusion on Primary Research Question ▪ Recommendations for Future Research

Chapter Seven concludes with a discussion of the conclusions and implications and arising from this research and areas for further investigation.

Chapter Two: Science Communication and Its Measurement

2.0 Introduction

Science communication and public participation involve two dominant priority groups: the science community and the public. Science has been diversely regarded as "an autonomous republic; a driver of innovation; the servant of society; something to be democratised and a fundamentally social process. Meanwhile publics are seen variously as: detached; a barrier to scientific and technological progress; ignorant of science and its methods and as vital actors in processes of knowledge creation" (Pallett, 2012, p.4). Public participation in its earliest forms consisted of abstract calls for open and transparent decision-making processes in science communication (Lengwiler, 2008). More recently, public participation has been heralded as a means to solve societal problems, enhance democratic process and reconstruct participants and their relationship with science (Zorn et al., 2010). Public participation in science communication is currently inhibited by a dichotomy of top-down technocratic approaches and bottom-up participatory processes (Stirling, 2008; Chilvers, 2009). To create meaningful change, attention should be diverted from the stylised contrasts of participation toward opening up the complex and nuanced understandings of analytic participatory processes in science communication (Stirling, 2008).

The purpose of this chapter is to understand the processes of participation, as the analytical understanding of participation in science communication represents the fundamental research gap within this study. In response, this chapter identifies the pluralistic enlargement of actors in participation through the policy, practice and public levels in science communication. The chapter then comprehends how participation has both guided and emanated from the progression of policy interfaces and societal paradigms within science communication. Through these progressions, theoretical gaps in the literature are outlined. The chapter concludes with a discussion on the contribution of this study where enhanced indicators can bridge the theoretical gaps in science communication.

A full outline of the themes discussed within this chapter is presented in Figure 2.0.

This chapter begins with the identification of the levels in science communication.

Figure 2.0 Overview of Chapter Two

2.0 Introduction

2.1 Levels in Science Communication

- Science Communication and Policy
- Science Communication and Practice
- Science Communication and the Public
- Summary of System Levels in Science Communication

2.2 Interfaces between Science Communication and Policy

- Sequential Models of the Interfaces between Science-Policy
- Participatory and Dynamic Science-Policy Interfaces
- Interfaces of Governance for Science-Policy
- Interfaces of Science-Policy Interaction
- Summary of Interface Models

2.3 The Co-Evolution of Science Communication Paradigms

- Science Literacy Paradigm
- Public Understanding of Science Paradigm
- Science-and-Society Paradigm
- Science-in-Society Paradigm
- Summary of Science Communication Paradigms

2.4 Theoretical Gaps in Science Communication

2.5 Bridging the Gaps in Science Communication through Indicator Measurement

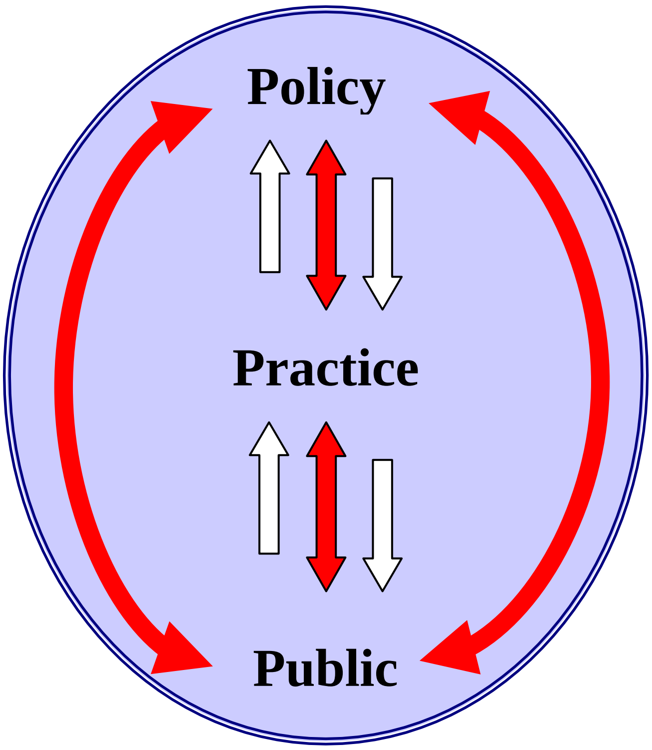
- Indicator Measurement
- Limitations of Indicator Measurement
- The Need for Enhanced Indicators in Science Communication
- A New Generation of Indicators

2.6 Chapter Summary

2.1 Levels in Science Communication

Changing visions of science communication and the conceptualisation of scientific expertise have been co-produced with imaginations of the public and its proper role in science policy deliberation processes (Pallett, 2012). To reflect this comprehension of co-production, three overarching levels are involved in the deliberation processes of science communication namely; policy level actors who are responsible for the governance of science communication (Knight and Barnett, 2010); practitioners who mediate between science, society and policy (Martin-Sempere, Garcon-Garcia and Rey-Rocha, 2008); and the public who engage in science (Irwin, 2008; Trench, 2008). The three levels, as illustrated in Figure 2.1, encapsulate policy, practice and the public. The top level of policy contains an inextricable link with science communication as policy makers govern the opening up and closing down of public participation in science communication (Stirling, 2008).

Figure 2.1 Three Levels in Science Communication



Adapted from: Glicken (1999); Weigold (2001); and Lujan and Todt (2007)

The interlinked relationship between science communication and the levels of policy, practice and the public are now examined.

2.1.1 Science Communication and Policy

The interlinked relationship between science communication and public policy has come under close scrutiny in recent years by theorists such as Bradshaw and Borchers (2000), Jones (2010) and Knight and Barnett (2010). Bradshaw and Borchers (2000) illuminate an emergent science-policy gap where the process of science is continually changing, so much so that science itself now precedes policy (Jones, 2010). The prolific gap between policy and science unnerves the policy level as the "spontaneity and speed of scientific developments appear to outpace consultation processes" (Knight and Barnett, 2010, p.387), exasperating the tandem development of science with policy.

To realign the tandem development of policy with science, Bradshaw and Borchers (2000) in line with Guston (2001) advocate for the blurring of boundaries between science and governments. Lyall (2007, p.5) examines more closely a policy networked approach which "takes account of the influence of various governmental and nongovernmental actors at different stages in the policy process and emphasises the linkages among these actors to explain policy-making". Bradshaw and Borchers (2000) do not advocate a networked approach; instead, the authors predicate that the most familiar approach to retracting the science-policy gap is to directly enhance public confidence in science through communication. The meaningful communication and education of science with concerned citizen groups, lobbyists and scientists translate into policy outcomes which are more likely to be consensus-based and less prone to legal challenge from disaffected stakeholders (Bradshaw and Borchers, 2000).

Chilvers (2008) notes however that while bottom-up public participatory processes in science-policy are critical, it is easy to forget that the majority of public participation occurs toward the end of policy processes. Communicating with the public at the end of science-policy deliberation processes often disempowers, excludes, oppresses and acts as a smokescreen behind which decision-making institutions conduct business as usual (Chilvers, 2009).

The reduction of the escalating science-policy gap requires collaboration processes beyond the traditional dyads of the policy level with the science community (Bradshaw and Borchers, 2000). Lujan and Todt (2007, p.97) argue that the "relationship between science and policy, in the form of policy for science (policies for promoting science and technology) as well as science for policy (scientific knowledge as basis for regulation and decision making)" increases public concerns of mistrust and unease with science (Allum, Sturgis, Tabourazi and Brunton-Smith, 2008). Consequently, the governance of science is shifting towards a triadic relationship where policy attention is refocusing on new deliberation methods for fostering engagement with stakeholders and the public (Stirling, 2008). The engagement of the public in policy deliberation processes enhances the role of science communication. Science communication emphasises participation between policy levels and the public which achieves better ends "such as, increasing public trust and the legitimacy of governing institutions, enhancing the acceptance and implementation of policies or reducing conflict surrounding decisions" (Chilvers, 2009, p.402). Communication, collaboration and participation between policy levels and the science community and policy levels with the public can lead to more productive, efficient and effective policy coordination processes for science communication.

2.1.2 Science Communication and Practice

The practice level of science communication includes stakeholders who have a desire to mediate science to both the public level and the policy level. According to Weigold (2001); Brossard and Shanahan (2006); Martin-Sempere, Garzon-Garcia and Rey-Rocha (2008) and Turner (2008) news organisations, journalists, scientists, science educators, science outreach officers and science communicators are all key actors who represent science at the practice level. Brossard and Shanahan (2006) contend that the media is the most and sometimes only available outlet for the public to learn about science. Hansen (2009) identifies a key problem in the medialization of science, where the mass media are treated as one homogenous group with little differentiation. In response, Weigold (2001) accepts that the modern coverage of science varies considerably within and across media sources such as newspapers, news organisations and television. Weigold (2001) also contends that the majority of journalists reporting on science do not possess a background or qualification in the area and consequently, writers learn science on the job. From this perspective, Gregory and Miller (1998) acknowledge two types of journalists who cover science news: journalists and science journalists. The medialization of science highlights the "profusion of media images, the diversity of media, the blurring of boundaries between media genres and most particularly the increasingly diverse nature of public consumption of media images, therefore, it would be futile to attempt to identify a single relationship between science in the media and public perceptions, attitudes and understanding" (Hansen, 2009, p.117).

The media serve an important role in science communication, as do the science community and the scientists themselves. Martin-Sempere, Garzon-Garcia and Rey-Rocha (2008, p.349) profess that "scientific practice and the profession are evolving in a way that should make scientists respond more positively to the need to improve the general public's access to science and should encourage them to take part in activities to improve the public understanding of science". Mogendorff et al. (2012) recognise the ways in which scientists should or best communicate with society has changed as society has salient knowledge and opinions relating to science. Weigold (2001) argues that scientists are hindered in their ability to communicate directly and bidirectionally with the public as they have had little experience in this form of direct communication, and there are apparent linguistic differences between scientists and the public.

To reflect this comprehension of inexperience, Martin-Sempere, Garzon-Garcia and Rey-Rocha (2008) express that scientists' lack training in public communication, inexperience and the reluctance to become involved in science communication is further fuelled by the negative reaction of colleagues, the need to adapt work habits, and communicating science to an unfamiliar audience (Martin-Sempere, Garcon-Garcia and Rey-Rocha, 2008). Weigold (2001) also explores the conflicts which arise between the science communities as fellow scientists view the medialization of science as trivial and compromising to a scientist’s integrity, as well as the fact that the public may get excited about the wrong side of the science story.

In addition to scientists and the media, science educators also share in the responsibility of imparting scientific wisdom (Brossard and Shanahan, 2006; Turner, 2008). Turner (2008) stalwartly proposes five critical reasons for science education; economic, utility, democratic, social and cultural arguments. The desire to become an innovative knowledge based economy is dependent on the supply of a well-qualified, scientifically literate public (Brossard and Shanahan, 2006). The development of an innovative economy is not only dependent on the formal education of science but is also reliant on the informal communication of science to the general public through science communicators and outreach officers. Bell (2008, p.387) stipulates that science communicators must incorporate “societal value and decision making into their educational offerings” to render the communication meaningful to the general public.

There are many stakeholders involved at the practice level of science communication. In addition to their interaction with the public, several of these actors can be interlinked with policy processes. Hessels, VanLente and Smits (2009, p.389) examine more closely the complexity of science as policy makers delegate deliberation processes to the practice level because policy makers “lack the capabilities or the knowledge that scientists have”. The multiplicity of roles at the practice level means that practitioners in all capacities are in constant contact with both the policy level and the public level.

2.1.3 Science Communication and the Public

The public are a critical level in science communication as scientists endeavour to increase the public’s awareness of science, understanding of science, participation in science and engagement with science (Davison et al., 2008). Hansen (2009) critiques the homogenisation of the public into one definitive group. The demarcation of the public into several classification typologies has been recommended by Miller (1992), Pardo and Calvo (2002); Burns, O’Connor and Stocklmayer (2003) and Braun and Schultz (2010).

Miller (1992) demarcated the first classification typology of the public. The classification by Miller (1992) comprises of three separate, yet inter-related groups based upon the public's interest in and desire to engage with science. Miller, (1992) classification includes the attentive public; the interested public; and the residual public. Miller (1992) acknowledges in precise form how there are very many publics with different attitudes, behaviours and cognitions towards science. Tytler, Duggan and Gott (2001) also categorise the multiple subsets of the public into the attentive, interested and non attentive. The heterogeneous nature to a public is further clarified by Burns, O'Connor and Stocklmayer (2003, p.184) when they define the public as "every person in society". Burns, O'Connor and Stocklmayer (2003, p.184) claim there are several facets to the public "each with its own needs, interest, attitudes and levels of knowledge" comprising of the general public; the attentive public; and the interested public.

The classification perpetuated by Burns, O'Connor and Stocklmayer (2003) concurs with the thinking of Miller (1992). In addition to the public level, Burns, O'Connor and Stocklmayer recognise the three levels of policy, practice and the public in their classification typology. Pardo and Calvo (2002) assert the same three subsets of the public, where they deem the public can be disaggregated into the attentive, the interested and the rest of the public. Glicken (1999), in opposition to Pardo and Calvo (2002) and Burns, O'Connor and Stocklmayer (2003) does not operationalise the public according to their attitudinal dispensation towards science but instead categorises the public into two clusters, comprising of institutions and structures as well as individuals and groups; each with its own needs, interests, attitudes and levels of knowledge. Glicken (1999) suggests that dyadic clustering approaches have diverse ways to achieve particular ends, use divergent analytic tools to achieve those ends and generally concentrate on different types of knowledge, communication and outcomes.

Braun and Schultz (2010) determine that there are four major constructions of the public including the general public; the pure public; the affected public; and the partisan public. Braun and Schultz (2010) are similar in their thinking to previous typologies where the public have been categorised according to their attitudinal orientation with science. Braun and Schultz (2010) demarcate the public according to their opinions and interests on scientific issues where the affected public become a dominant typology of opinion as these publics have direct or first hand experience of the consequences of science.

In spite of the seemingly divergent typologies of the public, the authors appear to be converging on a broad consensus that the public cannot be delineated to one homogenous classification such as the laity (Dornan, 1990). Instead, the public are heterogeneous in nature and are motivated by science in different ways.

2.1.4 Summary of System Levels in Science Communication

The three levels of policy, practice and the public in science communication embellish complexity and multiplicity. The most complex and ambiguous level to conceptualise is that of the public. Stakeholders from the practice and policy levels need to move away from the traditional classification of the public as a homogenous laity (Dornan, 1990), and embrace the multiple classification typologies of the public presented by Miller (1992), Pardo and Calvo (2002); Burns, O'Connor and Stocklmayer (2003) and Braun and Schultz (2010). The attentive, interested and non-affected publics (Miller, 1992; Burns, O'Connor and Stocklmayer, 2003) have "salient knowledge and critical perspectives that should be taken seriously as inputs into planning and designing" policies and strategies for science communication (Mogendorff et al., 2012, p.728).

The three levels of science communication are iterative and recursive in nature as knowledge and information moves within and across policy, practice and public levels. The public are no longer constricted to a submissive role in science communication; they are becoming active and involved contributors to science, where society now co-produces scientific knowledge in a democratic society (Glicken, 1999; Pallett, 2012). The mobilisation of a democrative society is hindered by the lack of integration, insight and understanding at the policy level of the knowledge, abilities and critical perspectives of the multiple stakeholder groups in the practice and public levels. Lengwiler (2008) as well as Stirling (2008) advocate that a democratic society should not only emphasise the pluralistic enlargement of actors in a decision process but also reflect on the eventual closure of such a process.

This section explored the three levels of policy, practice and the public in science communication. The next section will further examine the interlinked relationship between science and public policy through four science-policy interface models.

2.2 Interfaces between Science Communication and Public Policy

Science communication and public policy interfaces are social processes that entwine the policy, practice and public levels and "allow for exchanges, co-evolution and joint construction of knowledge with the aim of enriching decision-making" (Van der Hove and Sharman, 2006, p.186). Science and public policy have become interwoven in a longstanding relationship which is fraught with complexity and uncertainty as the gap between science-policy widens (Bradshaw and Borchers, 2000). The European Commission (2009) argues that if policy makers are not available to the scientific community or the channels of communication are not opened, then policy makers will be unable to make the best decisions on tough challenges facing an economy. Van der Hove and Sharman (2006, p.189) caution that interfaces between science and policy are not "one shot processes that would occur and then be followed by a policy decision that would solve the problem". Ideas and knowledge need to be produced and exchanged and co-produced and co-exchanged between the levels of science communication (Pallett, 2012). Within science communication, there is no definitive interface model to capture the exchanges between the levels of policy and practice. Instead, this section examines the four most prominent interface models between science communication and public policy:-

- A Sequential Model (Funtowicz, 2006);
- A Participatory and Dynamic Model (Van der Hove and Sharman, 2006);
- A Governance Model (Hagendijk and Irwin, 2006); and
- An Interaction Model (Pulzl and Rametsteiner, 2009).

The emergence of these interface models depicts the historical, cultural and political influences on science communication. Bora (2005, p.1) put the challenge facing the science-policy interfaces most succinctly when the author contended that the "simple linear model of explaining science to the public has been replaced by a complex, systemic, multi-directional and multi-linear concept. This concept is more interactive in the way of a citizen push approach promoting innovation with and for everyone". Societies have reached an inflection period in science-policy interface models, attributable to the emergence of decentralised governance modes in addition to the reliable presence of traditional forms of centralised control (Inzelt, 2008). Jones (2010, p.15) maintains that "getting science policy right is a key role of government, and arguably, the preeminent role of government in terms of fostering increasing economic prosperity". Each of the four interface models provides valuable insights into how science-policy interfaces progress over time, whilst optimising the participation of policy, practice and public levels in science communication.

2.2.1 Interface One: A Sequential Model

Funtowicz (2006) proposes a sequence of conceptual models of the interfaces between science and policy which evolve in five stages: Perfection/perfectibility: The Initial Modern Model; The Precautionary Model; The Model of Framing; The Model of Science/Policy Demarcation; and The Model of Extended Participation. The periodisation of science communication in Ireland from the 1950s co-aligns with Funtowicz's (2006) sequential model of the interfaces between science and policy as illustrated in Figure 2.2.1. Ireland's period of discovery in science policy is comparable to the modern, precautionary and framing models outlined by Funtowicz (2006). Ireland was heavily involved in attracting overseas investment, while increasing the numbers of graduates in science and its related disciplines of technology and engineering. In essence, Ireland was 'framing' the role of science in society. The period of conceptualisation marries well with the model of science/policy demarcation, as science institutions were emerging with clearly defined roles and responsibilities in the policy formation processes. The period of enlightenment marries well with Functowicz's (2006) model of extended participation. Policies concerning the opening up of science and the creation of science communication enterprises advocate the inclusion of the public in scientific discourse. Ireland is still in the embryonic stages of embracing the model of extended participation, which endorses a decentralised and collaborative approach to policy coordination.

Figure 2.2.1 The Application of the Sequential Model to the Periodisation of Science Communication in Ireland

Period of Discovery (1950 – 1970s)	Period of Conceptualisation (1980 – 1990s)	Period of Enlightenment (2000 – Present)
The Initial Modern Model The Precautionary Model The Model of Framing	The Model of Science/Policy Demarcation	The Model of Extended Participation

- **Perfection/ perfectibility: The Initial Modern Model**

For Funtowicz (2006), there is an implied assumption in the initial modern model that scientific facts, employed in rigorous demonstrations, determine correct policy. The classical view of facts determining correct policy epitomises the overarching and exemplary role of science in public policy. Pulzl and Rametsteiner (2009) delineate more closely the derivation of facts. Accordingly, "science is seen as a place of knowledge production and is supposed to produce facts. The scientific production of facts is considered to be value-free. Policy on the other hand is viewed as employing facts generated by scientific activity. It is conceptualised as a place of knowledge use. Political activities in this regard are considered to be value- and power-driven" (Pulzl and Rametsteiner, 2009, p.745). Van der Sluijs (2007) maintains that science assumes a position of autocratic control in the initial modern model, as science informs policy by producing objective, valid and reliable knowledge. Autocratic governance is also upheld by authors such as McGuire and Olson (1996) and Swyngedouw (2000). The initial modern model initiates that there are no limits to the exertion of scientific control over the environment (Funtowicz, 2006).

Pulzl and Rametsteiner (2009) characterize the clear segregation of values from facts as a linear boundary between science and governments. Science in the modern model exudes control, autonomy and in some ways aligns itself to a unilateral form of centralisation (Inzelt, 2008).

Van der Sluijs (2007) contends that the modern model exhibits several limitations. Firstly, the objectivity, validity and reliability of scientific knowledge pertaining to policy are highly scrutinized. Funtowicz (2006) furthers the knowledge argument by addressing the source of the knowledge, with particular emphasis on the role of the scientist. Although Pulzl and Rametsteiner (2009) separate facts and values in the scientific and political domains, Funtowicz's (2006) perspective argues that the modern model does not distinguish the collective generation of objective scientific facts from the value-laden contributions of policy and decision makers in governance. The impetus towards objective policy measures necessitates that the input of scientific facts in the policy process must be received from scientists who are independent to the political system in power.

Van der Sluijs (2007) critiques the initial modern model for presupposing that uncertainty can be eliminated, or at the very least controlled. Uncertainty is also a contentious issue in the science-policy interface as Bradshaw and Borchers (2000) contend that the uncertainty – or the lack of confidence in scientific facts emanates from both the public and policy makers. The initial modern model demonstrates similar elements to the information-transmission style of communication whereby science speaks truth, and thus, informs policy.

- **The Precautionary Model**

The uncertainties eliminated in the modern model appear at the forefront of the precautionary model. This model addresses the imperfections of science, unravelling "that the scientific facts are neither fully certain in themselves nor conclusive for policy" (Funtowicz, 2006, p.139). The precautionary model dissolves the autonomous control the modern model exalted over social processes, economic systems and the environment. Stilgoe and Wilsdon (2009) view the precautionary principle as an important axiom that informs decision making regarding complex techno-scientific issues. Funtowicz (2006) claims that the model is not a means to an end in itself; rather it advances the principles of the modern model to incorporate precaution in policy formulation. The precautionary principle conveys how science is still intrinsically significant to the development of policies, yet it now yields a moderate influence within the system of science compared to the autocratic role of the initial modern model (Van der Sluijs, 2007).

- **The Model of Framing**

Funtowicz (2006) postulates that in the absence of conclusive facts, scientific information becomes one of many inputs functioning as evidence in a policy deliberation process. The framing model advocates a participatory and contributory role of science in public policy, eliminating the hierarchical and autocratic powers of the previous modern and precautionary models. Inzelt (2008) concurs with the elimination of hierarchical levels, suggesting that stable relationships which are non-hierarchical in nature allow governments and the science community to work together on policy agendas as opposed to controlling and driving agenda processes.

Funtowicz (2006) highlights that policy debates surrounding scientific issues are necessary between the levels of science communication, as stakeholders in the decision making process have their own perspectives and values which shape their arguments (Funtowicz, 2006). The emergence of a scientific problem compels an integrative method of investigation, as the multiple levels of science communication determine which ideas contribute to the best outcome for policy, regardless of ownership of knowledge, power and control. The framing model emphasises a two-way democracy where science learns about science through contribution (Tlili and Dawson, 2010). Funtowicz (2006) highlights a limitation of the framing model where the incorrect framing of scientific problems hinders subsequent methods of investigation in policy coordination. Incorrect framing of policy problems due to “error, ignorance and/or poor judgement amounts to a misuse of the tool of scientific investigation” (Funtowicz, 2006, p.140), producing solutions which may not accurately address the societal or policy issue of the moment. Funtowicz (2006) and Van der Sluijs (2007) emphasise that framing is innately difficult as it entails an acceptance of the arbitrariness of choice and the possible misuse of science in the policy context.

- **The Model of Science/Policy Demarcation**

Funtowicz (2006) demarcates the explicit boundaries between science and policy which underpinned its predecessor model of perfection. Van der Sluijs (2007) ascertains that the model of science/policy demarcation rescues the modern model from conflicts of interest. Science and policy are viewed as separate entities with obvious boundaries and agendas. Policy is intrinsically associated with values, while science is predominantly orientated by facts (Pulzl and Rametsteiner, 2009). The demarcation model supports the separation of values from facts as their overlapping integration can lead to value-laden and subjective policies. The clear division of science from policy ensures that political accountability rests with policy makers and is not inadvertently transferred to the scientist (Funtowicz, 2006).

Funtowicz (2006) alludes to the risks of separating scientific institutions from the policy process. If the separation between policy and science is too great, science communities may place higher importance on pursuing their own self-interested goals of discovery and evaluation over their participation in the co-framing of policy issues. The model then becomes embodied in further ambiguity as science is no longer horizontally positioned to policy. Policy makers exert control at the top of the hierarchy, reverting to a centralised top-down model of governance (Inzelt, 2008). Hessels, VanLente and Smits (2009, p.389) contend that demarcation creates four fundamental problems for policy makers in “getting scientists to do what politics want; being sure they choose the best scientist; being sure that scientists do their best to solve the problems delegated to them, and knowing what to do”. Ensuring political accountability rests with policy levels and scientific accountability rests with science necessitates a balanced form of demarcation, which becomes the priority task of governance.

- ### The Model of Extended Participation

The preceding models are entrenched in imperfection, misuse and abuse of the dividing roles of science and policy, relating to power, coercion, autonomy and authority. In the model of extended participation, Funtowicz (2006) highlights that science; understood as the activity of technical experts is to be included as one part of the relevant knowledge that is brought in as evidence to a decision or policy process. Participation is critical to the determination of what the model represents. The model supports the notion that "citizens should become both critics and creators in the knowledge production process" (Funtowicz, 2006, p.141). The model encourages a decentralised approach to governance, which is also advocated by Inzelt (2008) where both the experts and the public become involved in an interactive and iterative process of communication, resulting in the co-production of knowledge and value, alongside the process of mutual and reciprocal learning (Van der Hove and Sharman, 2006; Pallett, 2012).

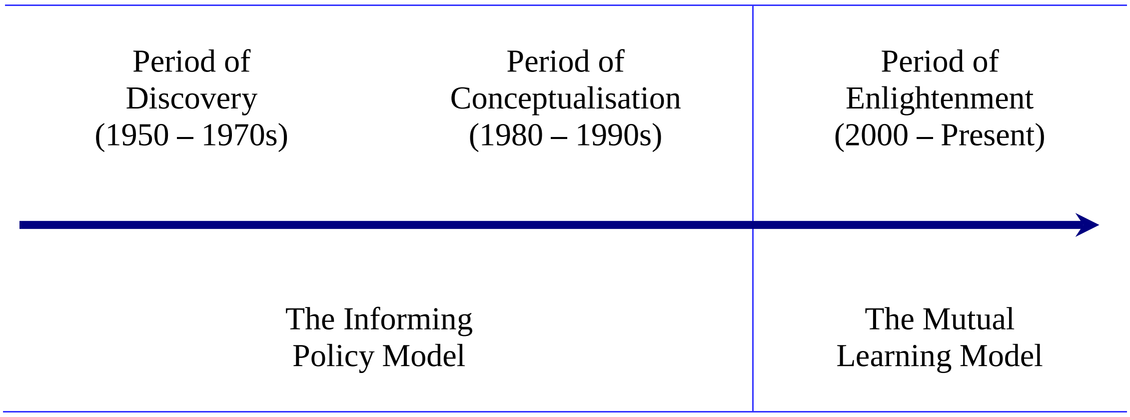
Funtowicz (2006) proposes that the adoption of a pluralistic and participatory view of knowledge production is necessary to deal with contemporary knowledge problems. Cotic-Svetina, Jaklic and Prodan (2008) in parallel with Adeoti and Olubamiwa (2009) assert that a participatory style to knowledge exchange enhances understanding, encourages trust, and results in collective learning. Cotic-Svetina, Jaklic and Prodan (2008, p.336) define collective learning as a "social process of learning, based on a set of shared rules and procedures that allow individuals to coordinate their actions in search of a problems solution". Roberts (2000) contends that collective learning is compatible to a collaborative strategy in that it too highlights the collective aspect, articulating a collaborative strategy is "premised on the principle that by joining forces parties can accomplish more as a collective than they can achieve by acting as independent agents" (Roberts, 2000, p.6).

In summary, the sequential interface model of Funtowicz (2006) illustrates a progressive relationship between science and public policy. Science and policy have shifted from autocratic models of top-down separation to participatory models of knowledge co-production (Pallett, 2012). Dealing with contemporary knowledge problems "requires opening the analytical and formal decision-making processes to broader categories of facts and actors than those traditionally legitimated" (Funtowicz, 2006, p.142). Funtowicz's (2006) sequential interface model acknowledges the bifocal roles of science and policy. The modern, precautionary and framing models clearly define the tasks, abilities and intellectual knowledge sets of both policy makers and science. The model of demarcation produces a beneficial outcome as scientists and policy makers are partitioned according to their knowledge sets and expertise, as scientific accountability rests with science and political accountability is the role of policy. Once accountabilities are identified and accepted, the science communication levels can co-exchange ideas and co-produce solutions as the stakeholders are acutely aware of their individual accountabilities within the process of coordination (Van der Hove and Sharman, 2006; Pallett, 2012). The next interface model also emphasises the dyadic shift from technocratic approaches to participatory processes in science communication.

2.2.2 Interface Two: A Participatory and Dynamic Model

Van der Hove and Sharman (2006) present a dichotomous interface model where science-policy relations embrace two dominant forms: the informing policy model and the mutual learning model. Like Funtowicz (2006), Van der Hove and Sharman's (2006) participatory and dynamic interface models can be applied to the science communication epochs in Ireland, as illustrated in Figure 2.2.2. The informing policy model is apparent throughout the periods of discovery and conceptualisation in Irish science communication, as governments and policy makers' commanded control and power at the top of the hierarchical communication chain. The mutual learning model of policy emerged in the period of enlightenment as policy and practice levels began to see the value of including the voice of the public in policy deliberation processes (Stirling, 2008; Lengwiler, 2008; Chilvers, 2008; 2009).

Figure 2.2.2 The Application of the Participatory and Dynamic Model to the Periodisation of Science Communication in Ireland



- **The Informing Policy Model**

Van der Hove and Sharman (2006) suggest that the informing policy model assumes a clear division between the scientific production process and the communication of results to influence and shape policy. The informing policy model segregates policy makers and the science community into two distinctive and unrelated domains. The informing policy model is "grounded on positivist ideals of objectivity and neutrality" (Van der Hove and Sharman, 2006, p.190), accentuating the separation between fact-driven data and value-laden perspectives. Informing science-policy processes exhibit sequential and linear flows of knowledge production from the science community to the policy level. Informing policy models are viewed as an independent pursuit of self-validating knowledge unaffected by the changes and progressions in social, cultural and economic spheres (Tlili and Dawson, 2010). To this end, informing models reflect a mechanical transmission style of coordination where the transfer of expert scientific knowledge from the science community to the policy level is the axiom guiding coordination and communication processes (Gregory and Miller, 1998).

- **The Mutual Learning Model**

Van der Hove and Sharman (2006) maintain the mutual learning model coincides with a participatory vision of both the policy and the scientific process. Mutual learning blurs the boundaries between science and governments when dealing with complex policy and societal issues. Mutual learning views the relationship between science and policy as a progressive process. Mutual learning recognises that "any scientific endeavour is inextricably intertwined with values and power issues" (Van der Hove and Sharman, 2006, p.190). Mutual learning models acknowledge the constant evolution of knowledge which needs to be shared between policy makers and the science community to lessen the science-policy gap, ensuring the tandem development of science with policy (Bradshaw and Borchers, 2000; Jones, 2010).

In summary, Van der Hove and Sharman (2006) acknowledge the presence of informing policy models and mutual learning models and even proliferate that the two models co-exist through participation. Participatory processes allow for "the various and often irreconcilable values underlying problem definition and social choices to be explicitly introduced and accounted for in the scientific quality process" (Van der Hove and Sharman, 2006, p.191). The co-existence of informing policy models with mutual learning models reflects the opening up and closing down mentality of Stirling (2008) in regards to the participation of the public in science-policy deliberation processes. Opening up and closing down policy coordination processes acknowledges that the actors and institutions which co-produce change may evolve and transform over time depending on the societal and policy issues under consideration (Stirling, 2008).

The next interface model reflects the co-existence ability of science-policy interfaces through the discussion of several modes of governance.

2.2.3 Interface Three: A Governance Model

Hagendijk and Irwin (2006) present a typology of governance modes which describe various forms of engagement. Hagendijk and Irwin (2006) highlight six typologies of governance which include discretionary, corporatist, educational, market, agonistic and deliberative modes. As highlighted with preceding interface models, Hagendijk and Irwin's (2006) governance model can be applied to the periodisation eras of science communication, as illustrated in Figure 2.2.3.

Figure 2.2.3 The Application of the Governance Model to the Periodisation of Science Communication in Ireland

Period of Discovery (1950 – 1970s)	Period of Conceptualisation (1980 – 1990s)	Period of Enlightenment (2000 – Present)
Discretionary Governance Corporatist Governance Educational Governance	Market Governance Agonistic Governance	Deliberative Governance

Hagendijk and Irwin's (2006) heuristic typologies can be summated as follows:

1) *"Discretionary governance is carried out in a context where progress depends on the absence of the public from policy processes;*
2) *Corporatist governance involves the recognition of different interests in policy processes in search for consensus;*
3) *Educational governance is carried out and justified through the notion of public ignorance as important for efforts in creating an informed citizenry;*
4) *Market governance is characterised by the regulation of science and technology through its value for commercialisation and for building societal public wealth;*
5) *Agonistic governance is seen as a counterpart to corporatist modes of governance striving towards consensus and fundamentally opposes the ideal of liberal democracy; and*
6) *Deliberative governance opens and engages public debate as a way of creating a foundation for decisions concerning the role of science and technology in society" (Bragesjo, Elzinga and Kasperowski, 2012, p.68).*

Hagendijk and Irwin (2006) highlight the progression of science-policy interfaces where the public were purposefully omitted from the deliberation processes in discretionary governance modes to the direct inclusion of public participation in the deliberative governance mode. Governance modes accept the critical role of the public in deliberation processes whilst also acknowledging the limited capabilities and perspectives of the policy and practice levels. Hagendijk and Irwin (2006) caution that there is no unitary principle of governance, but rather a complex pattern of intersections where science-policy interfaces evolve back and forth from discretionary to deliberative modes of governance.

Hagendijk and Irwin (2006) indicate that sometimes governance modes are chosen as a response to international competitiveness compared to the desire of being responsive to the public. The limited responsiveness towards the public often acts as a smokescreen behind which decision-making institutions conduct business as usual (Chilvers, 2009). The omission of public values in policy deliberation processes can render subsequent participation processes futile, as citizens feel betrayed and disempowered by disingenuous acts of public participation (Chilvers, 2009). The choice between governance modes requires a responsiveness balance between international competitiveness and public inclusion. The next interface model replicates Van der Hove and Sharman's (2006) participatory and dynamic model of science-policy interfaces.

2.2.4 Interface Four: An Interaction Model

Pulzl and Rametsteiner (2009) make fruitful reference to two interaction models, namely a transaction model and a transfer interaction model. Like previous interface models, Pulzl and Rametsteiner's (2009) interaction models can be applied to the science communication periods in Ireland, as illustrated in Figure 2.2.4. The transfer model reflects the thinking associated with both the period of discovery and the period of conceptualisation, while the transaction model intertwines its values and associations with the period of enlightenment.

Figure 2.2.4 The Application of the Interaction Model to the Periodisation of Science Communication in Ireland

Period of Discovery (1950 – 1970s)	Period of Conceptualisation (1980 – 1990s)	Period of Enlightenment (2000 – Present)
The Transfer Model		The Transaction Model
▪ Boundaries well delineated ▪ Separation of values and facts ▪ Linear interaction ▪ Instrumental use of knowledge		▪ Boundaries blurred ▪ Complex mixing of value and facts ▪ Interaction is non-linear ▪ Reflexive use of knowledge

Adapted from Pulzl and Rametsteiner (2009)

- **The Transfer Model**

The transfer model views the production of scientific knowledge as the task of the scientific community, while the political realm only uses the knowledge once it has been developed by the scientific community (Pulzl and Rametsteiner, 2009). The delineation of power between government and science extends Jones (2010) science-policy gap. A transfer model ensures that the production of knowledge is value-free and purely fact driven as science is seen as a “place of knowledge production and is supposed to produce facts” (Pulzl and Rametsteiner, 2009, p.745). The transfer model personifies the linear transference of scientific knowledge from the objective science community to the neutral policy level. Objectivity and neutrality protects science from the political interference that diminishes its integrity (Funtowicz, 2006). Rose et al. (2009) dispute the linearity of science, acclaiming it is often interactive and iterative as opposed to the sequential processes of knowledge production and knowledge transference between the science and policy spheres. The linear transfer model has been criticised for two reasons: first science-policy interfaces are seen as a progression between separate stages rather than interactions and feedback between different levels. Second, it places an overemphasis on research and development, rather than on non research and development inputs to policy deliberation processes (Sirilli, 1999). The limited capabilities of the transfer model results in the emergence of a transaction model of interaction.

- **The Transaction Model**

The transaction model "conceptualises (scientific) knowledge not as a ready-made product available to policy makers upon request, but knowledge input into the political process is to be seen as a dynamic social process. This process may change frequently over time and develops in iterative steps" (Pulzl and Rametsteiner, 2009, p.746). Pulzl and Rametsteiner (2009) build upon Functowicz's (2006) value appraisal where the authors recognise that a transaction model integrates fact-driven and value-driven judgements. Pulzl and Rametsteiner's (2009) transaction approach reflects a participatory interface for science-policy as the boundaries are blurred between politicians, practitioners and the public, which also reflects the thinking of Guston (2001). Guston (2001, p.399) finds that the blurring of boundaries between science and policy "rather than the intentional separation often advocated and practiced, can lead to more productive policy making". Transaction models for science-policy open up the processes of coordination where value judgements are mixed with the scientific truth, and multiple stakeholders and institutions from multiple levels in science communication contribute to the participatory approaches for deliberative science-policy democracies (Tlili and Dawson, 2010).

In summary, the transfer model approach embellishes a segregation of roles between science and policy. The sole responsibility of science is to produce fact-driven science knowledge and disseminate this knowledge to the policy domain. As such, the transfer model overlooks the salient knowledge of the stakeholders outside the perimeters of science. The transaction model capsizes the delineation of power and control, integrating the knowledge of all science communication levels, thus, creating a deliberative democracy of expertise (Pulzl and Rametsteiner, 2009).

2.2.5 Summary of Interface Models

Van der Hove (2007, p.809) suggests that “when searching for the domains of intersection between science and policy, we successively look at the outputs of science, its processes and its actors and its context”. In relation to the four interfaces between science communication and public policy, there are two thematic segregations. The first thematic segregation combines the initial modern model, precautionary model, framing model and model of demarcation of Funtowicz (2006) with the informing policy model (Van der Hove and Sharman, 2006), the discretionary, corporatist and educational governance modes (Hagendijk and Irwin, 2006) and the transfer model of interaction (Pulzl and Rametsteiner, 2009). These models create explicit boundaries between the science community and policy levels. The production of knowledge is the autonomous responsibility of science where science speaks truth. In this segregation, the public are omitted from coordination processes as science and policy levels prevail as the dominant contributors to knowledge co-production (Pallett, 2012).

The second thematic segregation embodies the model of extended participation presented by Funtowicz (2006) in addition to the mutual learning model (Van der Hove and Sharman, 2006), the market, agonistic and deliberative governance modes (Hagendijk and Irwin, 2006) and the transaction model of interaction (Pulzl and Rametsteiner, 2009). These models propose a fundamental change to the status of science in relation to its communication and involvement beyond the traditional science-policy boundaries of wisdom. To conclude, science-policy interfaces are not one shot processes that solve societal and policy issues (Van der Hove and Sharman, 2006; Zorn et al., 2010). Successful science-policy interfaces balance the ideologies of the two thematic segregations where informing, listening, learning and exchanging ideas and views become essential in creating science-for-science, science-for-policy, science-for-society and science-for-action (Burgess and Clark, 2006; Van der Hove, 2007).

The preceding discussion detailed four science-policy interface models. The next section highlights four paradigms in science communication. These four paradigms, like the science-policy interface models illustrate the progressive nature to science communication.

2.3 Science Communication Paradigms

The preceding discussion highlights the progressive nature to science-policy interfaces and inter-relates the theoretical interface models with the practice of science communication in Ireland. This section examines four science communication paradigms which co-exist in the literature. The theoretical paradigms of science literacy, public understanding of science and science-and-society and their influential contributors can be interconnected with the periodisation of science communication in Ireland, as illustrated in Table 2.3. Evidently, there has been an extensive amount of theoretical, practical and empirical work conducted in relation to the three science communication paradigms. Dijkstra and Gutteling (2012) propose that the traditional public-science relationship has changed, producing a fourth emerging paradigm of ***science-in-society*** which is championed by authors such as Bora (2005); Stirling (2006) and the European Commission (2009).

Table 2.3 Interconnecting Science Communication Paradigms with Science Communication Practice in Ireland

Period of Discovery (1950 – 1970s)	**Period of Conceptualisation (1980 – 1990s)**	**Period of Enlightenment (2000 – Present)**
Science Literacy Paradigm	**Public Understanding of Science Paradigm**	**Science-and-Society Paradigm**
Contributors:	*Contributors:*	*Contributors:*
Henriksen and Froyland, (2000); Pingree, Hawkins and Botta, (2000); Weigold (2001); Treise and Weigold (2002); Miller (2004); Brossard and Shanahan (2006); Falk, Storsdieck and Dierking (2007); Schafer (2009).	Schnabel (2003); Kim (2007); Michael (2009).	Glicken (1999); Wilsdon and Willis (2004); Bauer, Allum and Miller (2007); Burningham et al. (2007); Poliakoff and Webb, (2007); Bell (2008); Davies (2008); Martin-Sempere, Garzon-Garcia and Rey-Rocha (2008); Powell and Colin (2008); Yaneva, Rabesandratana and Greiner (2009); Miller, Fahy and the ESConet Team (2009).

These paradigms provide fundamental insights into the progression of science communication. Individually, each of the paradigms assists in the comprehension of the interaction styles and communication models between the policy, practice and public levels of science communication. When combined, the paradigms offer invaluable portrayals of the science communication process as a holistic system (Bora, 2005). Science-in-society recognises the holistic tenet to science communication and opens up to the integrative patterns of analytic participation compared to the stylised contrasts of participation in the preceding paradigms (Stirling, 2008). Despite the strong assertion that these paradigms co-exist in the literature (Trench, 2008), they are very much treated as sequential and evolutionary models of progression, where one model ends as the other begins. Although the interconnection table above illustrates a progressive dimension to the paradigms, it must be noted that this illustration intends to highlight the dominance of each of the paradigms throughout science communication practice as opposed to their lifetime span. All three science communication paradigms have their own uses in particular circumstances (Trench, 2008).

Each of the four paradigms concerned with science communication have borne with them certain traits, characteristics, attributions, ideologies and orientations. Trench (2008) alongside Irwin (2008); Bucchi (2008) and Bauer (2009) have collectively compared and contrasted the first three paradigms associated with science communication, as summated in Table 2.3.0. The next section critically examines these three paradigms in addition to the emergent science-in-society paradigm and their associated constructs, attributions and principles will be discussed.

Table 2.3.0 Key Constructs within the Science Communication Paradigms

Periodisation of Irish Science Communication	**Period of Discovery (1950 – 1970s)**	**Period of Conceptualisation (1980 – 1990s)**	**Period of Enlightenment (2000 – Present)**
Science Communication Paradigms	**Science Literacy Paradigm**	**Public Understanding of Science Paradigm**	**Science-and-Society Paradigm**
Attribution Diagnosis	Public Deficit Knowledge	Public Deficit Attitudes	Trust Deficit Expert Deficit
Communication Model	Dissemination; Education	Dialogue	Conversation; Engagement
Ideological and Philosophical Assumptions	Scientism; Technocracy	Pragmatism; Constructivism	Participatory democracy; Relativism
Communication Style	One-way; Top-down	Two-way, Bottom-up	Multiple Stakeholders; Multiple frameworks

Adapted from: Bucchi (2008); Irwin (2008); Trench (2008); Bauer (2009)

2.3.1 Science Literacy Paradigm

The paradigm of science literacy evolved between the 1960s and the 1980s with the coherent objective to increase science literacy among the general public (Bauer, 2009). Despite the strong argument for science literacy, there is no one pioneering definition in the literature. Authors such as Henriksen and Froyland (2000), Tytler, Duggan and Gott (2001), Miller (2004) and Brossard and Shanahan (2006) have put forward varying interpretations on what constitutes a scientifically literate population. Henriksen and Froyland (2000, p.393) designate that a scientifically literate person "means not only having an understanding of a range of scientific concepts and processes, but also being able to apply this understanding". Tytler, Duggan and Gott's

(2001, p.345) support the dimension of understanding, as the authors define a scientifically literate individual as “one who can achieve a functional understanding of, and response to, science-related phenomena that impact upon the individual’s life, including issues canvassed in the media”. Miller (2004, p.273) takes the perspective that there are fundamental requirements in the determination of a scientifically literate citizen which include “having a basic vocabulary of scientific terms and constructs and having a general understanding of the nature of scientific inquiry”. Brossard and Shanahan (2006, p.51) contend that a scientifically literate population can “understand, interpret and interrelate scientific phenomena with facility, and form relevant and independent conclusions from information acquired through the mass media of communication”.

Evidently, there is a consensus among science communication theorists on the need for scientifically literate citizens and the fundamentals that enable individual citizens to become scientifically knowledgeable. Brossard and Shanahan (2006) articulate that the debate still continues on what constitutes a scientifically literate population, and by extension, how the component is understood.

Pingree, Hawkins and Botta (2000) outline three levels of understanding for scientific literacy: cultural scientific literacy, functional scientific literacy and true scientific literacy. Cultural scientific literacy equates to the public being familiar with the words used in scientific discourse but their comprehension of their exact meaning is limited. Functional scientific literacy presides over the ability of the public to engage in meaningful debate or conversation of science, while true scientific literacy incorporates the ultimate understanding of scientific processes and its role in society.

Bauer, Allum and Miller (2007, p.80) stratify scientific understanding in an alternative way by deducing scientific literacy into four elements including “knowledge of basic textbook facts of science; an understanding of scientific methods; an appreciation of the positive outcomes of science and technology for science and the rejection of superstitious beliefs such as astrology or numerology”. Although the exact stratification of scientific literacy differs between the authors, they conclusively support the understanding of scientific facts and processes.

Pingree, Hawkins and Botta (2000) maintain that the public's cultural understanding of science is inadequate. The science community needs to translate the facts of science into simple straightforward terms to further the public's understanding of science in their everyday lives (Pingree, Hawkins and Botta, 2000). A scientifically literate population is important to an economy (Brossard and Shanahan, 2006). Manzini (2003) verifies the importance of literacy by indicating that scientifically literate societies are stronger economically due to the fact that a better informed citizenry can be more innovative. Henriksen and Froyland (2000), alongside Falk, Storsdieck and Dierking (2007) perpetuate the critical linkages between scientific literacy and the advancement of the democratic, economic, social and cultural values of societies. Notwithstanding, there is an increasing danger that stakeholders associated with the coordination and formulation of policy directives may view science as the ultimate panacea to developing and advancing economies structurally, competitively, culturally and economically.

Science communication theorists such as Bauer, Allum and Miller (2007) argue that it is naïve to assume science literacy is the ultimate solution to the progression of an economy; instead it is imperative to recognise that it is one crucial domain within the overall advancement of societies. Additionally, limitations and drawback to the science literacy paradigm have been raised by Tytler, Duggan and Gott (2001); Miller (2004) and Falk, Storsdieck and Dierking (2007).

Tytler, Duggan and Gott (2001) voice concerns over the term literacy, acclaiming it is too poorly defined to be useful for driving science education agendas. Miller (2004) compounds the views of Tytler, Duggan and Gott (2001) as he argues that literacy should be viewed as a series of separate measures – one for citizenship roles, one for consumer roles and one for a more general level of cultural understanding. The arguments are inter-related to the science attentive, interested and residual public classifications discussed earlier in section 2.1.3.

Another limitation of science literacy is highlighted by Falk, Storksdieck and Dierking (2007) as the authors suggest that science is about free-choice learning. Free choice learning allows the public to decide on whether or not they want to enhance their understanding of science as opposed to the traditional alternative of being educated. Free choice learning gives autonomy and power to the public where intrinsic motivations inspire the public levels consumption and understanding of science. The absence of free choice learning through extrinsic motivations means the choice of literacy no longer resides with the public (Falk, Storksdieck and Dierking, 2007) and autonomy and power is transferred to policy and practice levels.

In summary, the paradigm of increasing the public's scientific literacy is similar to the information-transmission model of communication discussed in chapter one. The issue of literacy becomes more prominent when it is twinned with the consequential outcome of a deficit model in the science communication literature.

2.3.1.1 The Science Literacy Deficit Model

According to Bauer, Allum and Miller (2007, p.80) "the literacy idea attributes a knowledge deficit to an insufficiently literate public. This deficit model serves the education agenda, demanding increased efforts in science education at all stages of the life cycle". The notion of a deficit model among the general public is a recurring theme among authors in the science communication literature such as Sturgis and Allum (2004); Wilsdon and Willis (2004); Bauer, Allum and Miller (2007); Kim (2007); Trench (2008); Bauer (2009); and Davies et al., (2009).

The deficit model in the literacy paradigm revolves around knowledge (Bauer, 2009). Pingree, Hawkins and Botta (2000) alongside Besley and Tanner (2011) and Davies et al. (2009) attribute the deficit model to the public. Pingree, Hawkins and Botta (2000) assert that the public is not yet sufficiently aware of the words used in scientific discourse. The inability of a public to comprehend the basic terms in science affects the attainment of functional and true scientific understandings in society. Besley and Tanner (2011) contend that the publics' sceptism toward modern science is caused by a lack of adequate knowledge about science. For Davies et al. (2009), there is an implicit assumption that the public are deficient in knowledge, understanding and agency.

Burns, O'Connor and Stocklmayer (2003, p.189) advocate that a deficit model "characterises the public as having inadequate knowledge, and science as having all the required knowledge”. Likewise Sturgis and Allum (2004, p.57) suggest that “it is the public that are assumed to be deficient while science is sufficient”. Allum, Sturgis, Tabourazi and Brunton-Smith (2008) would even go as far as to say that the deficit model assumes people are resistant to learn about science because of their own fears, superstition, ignorance and mistrust. In order to overcome the alleged ignorance of the general public (Allum, Sturgis, Tabourazi and Brunton-Smith, 2008), the science community saw public education as the most suitable intervention method (Bauer, Allum and Miller, 2007).

Winter (2004) and Davies et al. (2009) compared the public to empty vessels ready to be filled with a collection of scientific facts and knowledge. Yaneva, Rabesandratana and Greiner (2009) conceived the transfer of scientific facts and knowledge from the science community to the public, as a unidirectional flow of knowledge. Martin-Sempere, Garzon-Garcia and Rey Rocha (2008) and Burns, O’Connor and Stocklmayer (2003) perpetuate the unidirectionally of science, where one-way communication flows delineate the public as passive and sometimes poorly qualified receivers of knowledge. Unidirectional communication associates the scientist as “having all the required knowledge” (Burns, O’Connor and Stocklmayer, 2003, p.189), and viewed somewhat as an expert (Kurath and Gisler, 2009). Kurath and Gisler (2009) argue that the mere transference of unidirectional information from the expert to the public reinforces the divisional segregations between the science community and the public. Practice and public levels became increasingly detached in the science literacy paradigm due to the didactic and educational approaches employed by the science community. Sturgis and Allum (2004, p.56) ascertain that the educational approach of creating awareness of science among the general public was producing further negativity as it lead to “public unease, mistrust and occasional outright hostility”. Trench (2008) maintains that scientists were consumed in a monologue process of science education as they transmitted their expert knowledge to the deficient public.

Educational challenges were not limited to the public level; the science community incurred tremendous difficulties in educating the public. Weigold (2001) posits that the most essential difficulty is language as scientists use scientific language when communicating with the public. Scientists need to translate their technical knowledge into a currency which will not detract the publics understanding of science (Weigold, 2001).

Pingree, Hawkins and Botta (2000) profess that scientists conceived the public to be at a functional level of scientific literacy where they could engage in a meaningful conversation about science, when in fact the public presided at the cultural level of scientific literacy. Gregory and Miller (1998) argue that the passive dissemination of knowledge from the scientist, in conjunction with the passive absorption of knowledge from the public will not automatically translate into increased levels of interest and literacy among the publics pertaining to science.

The deficit model associated with the literacy paradigm is fraught with immense challenges and difficulties. Sturgis and Allum (2004) accentuate several criticisms to the deficit literacy model. Firstly, Sturgis and Allum (2004) disapprove of the assumption that so called irrational fears of lay publics are based on a lack of scientific understanding, which in their opinion has been strongly challenged by several other commentators. Secondly, the way in which the deficit model has been approached via quantitative survey research and the selection of appropriate measures of scientific understanding has come under scrutiny, depending on the domains of knowledge influencing the research. Finally, Sturgis and Allum (2004, p.57) critique the way in which the deficit model suggests that "the effect of scientific knowledge is far outweighed by the influence of social trust on perceptions of new and potentially risky technologies".

Lewenstein (2005) maintains that labelling a person as scientifically illiterate highlights the hierarchical power relationships between those who have particular knowledge in one area and those who have not. In addition, Lewenstein (2005) contends that the public learn best, when facts and theories have meaning in their personal lives. If the unilateral knowledge transferred from the science community has no meaning to the public, they will find it increasingly difficult to recall that knowledge. Essentially, Lewenstein (2005, p.3) concludes that "despite all the rigorous activity in public communication of science and technology, defining and approaching the problem from the perspective of filling the deficit doesn't seem to have reduced the perceived problem; the deficit model does not seem to have been a successful approach".

Davies et al. (2009) continue the desolation of the deficit model. According to Davies et al. (2009, p.338) research showed that "publics' relations with science were much more complex than the deficit model suggested: individuals were active in handling scientific information, rather than passive; had their own forms of expertise which they applied to scientific knowledge; and – perhaps most importantly – interacted with science not in a vacuum but within social contexts and for social purposes". Davies et al. (2009) argue that the public are sufficiently able to appreciate science, providing the impetus to move away from the literacy domain.

To summate, the literacy paradigm assumes the public are insufficiently literate on topics relating to science. The illiteracy of the public is caused by a knowledge deficit (Bauer, 2009). To counteract this knowledge deficit, experts at the practice level of science (Kurath and Gisler 2009) communicated their knowledge to the public in the form of education (Bauer, Allum and Miller, 2007). The one-way flow of information from the practice level down to the public created unforeseen consequences for science communication, as the publics' knowledge deficit shifted towards an attitudinal deficit. This attitudinal deficit will be discussed in the next paradigm in science communication.

2.3.2 Public Understanding of Science Paradigm

Bauer (2009) documents the occurrence of the public understanding of science paradigm between 1985 and the 1990s. Burns, O'Connor and Stocklmayer (2003, p.187) define the public understanding of science as: "understanding of science content or substantive scientific knowledge; an understanding of the methods of enquiry and an understanding of science as a social enterprise". Borchelt (2001, p.199) reveals that an understanding of the public urges scientists to move away from "identifying what the public ought to know and to identify what they want to know and finding ways to make this knowledge available and accessible". The one-way flow of information from the practice level down to the public will not suffice in retrieving knowledge from the public.

Scientists now need to employ alternative methods of communication such as dialogue, as the task in this paradigm is less one of propaganda and more one of negotiation (Gregory and Miller, 1998). The science community becomes receptive to dialogical processes of informal learning in an attempt to create positive public attitudes to science (Van der Hove and Sharman, 2006). The public understanding of science paradigm constitutes a shift from deficit to dialogue (Wilsdon and Willis, 2004; Bucchi, 2008; Trench, 2008; Stilgoe and Wilson, 2009), where the public are no longer viewed as ignorant towards science. Instead, the public are viewed as salient contributors to the co-production of scientific knowledge (Pallett, 2012).

The move from deficit to dialogue raises critical views from theorists within science communication. The term dialogue is unclear and creates ambiguity among science communication theorists. Jackson, Barbagallo and Haste (2005) alongside Van der Sanden and Meijman (2008) are adamant in their views on what does not constitute dialogue. Firstly, Jackson, Barbagallo and Haste (2005) warn that dialogue is not primarily about scientists explaining how the world works to the passive laity (Dornan, 1990), nor does it remove authority or expertise from science. Van der Sanden and Meijman (2008) also warn that dialogue is not about playing a role in the science communication process nor is it about winning or convincing.

Instead, dialogue has been hypothesised as a negotiation of facts (Van der Sanden and Meijman, 2008); an open exchange for the sharing of knowledge (Jackson, Barbagallo and Haste, 2005); an open and egalitarian approach to communication (Schafer, 2009); a mutually informing and symmetrical process (Davies et al., 2009) for free-choice science learning (Falk, Storksdieck and Dierking, 2007). Although the above authors have varying outlooks on the constitution of dialogue, their divergent thinking appears to be converging on a more inclusive, open and symmetrical logic of exchange in the public understanding of science paradigm.

Kurath and Gisler (2009) critique the public understanding of science paradigm as the authors maintain that the credibility of science declines, even in times of intense dialogical activity. Van der Sanden and Meijman (2008) surmise that dialogue is not only concerned with informing the public about facts, concepts and fears but it is also concerned with notions and attitudes. The inclusion of an attitudinal component in the understanding paradigm shifts the deficit model towards an attitudinal deficiency.

2.3.2.1 Public Understanding of Science Deficit Model

Bauer (2009) alludes to the concept of an attitude deficit rather than a knowledge deficit in the public understanding of science paradigm. An attitudinal deficiency is not subsumed by the fact that one is not literate or illiterate, but more or less knowledgeable (Bauer, 2009). The majority of science communication authors do not advance the deficit model from its traditional knowledge perspective. However, the acknowledgement of an attitude deficit is crucial to the public understanding of science paradigm as the model is fixated in exchanging knowledge with the public, in an attempt to influence and shape attitudes (Bauer, 2009). Bauer (2009, p.224) maintains that “attitudes that are based on knowledge – whether positive or negative – are held more strongly and thus resist change”.

The public understanding of science paradigm is embroidered in a deliberative democracy as communication processes are shared and multi-directional (Logan, 2001). Scientists exchange their technical knowledge to the public, while the public reciprocate through the exchange of their lay knowledge and interpretations of scientific issues. Van der Sanden and Meijman (2008) imply that it is imperative for both kinds of knowledge to be exchanged in order to achieve meaningful dialogue between the science community and the public. Trench (2008, p.124) advises that dialogue is valuable “but it is a strict and jealous God. Dialogue’s law is not about self-expressive pleasure but rather self-denying listening”. The science community, under the guise of dialogue requests input from the public. However, these inputs do not shape or influence the communication process as scientists maintain their original stance and continue with science as usual (Stirling, 2008).

Trench (2008) cautions that science communication doe not come in a one-size fits all model called dialogue and thus, the entrenched notion that the public will become more favourable to science as they are exposed to more information threatens the integrity of the communication processes. The reflective learning which occurs resides once again with the public instead of the science community. Although the components of two-way communication, dialogue and learning exist in the public understanding framework; there is still a clear and palpable demarcation between science and the public (Funtowicz, 2006).

In summary, the public understanding of science paradigm affords scientists the opportunity to bi-directionally communicate with the public to identify what they want to know and find ways to make this knowledge available (Borchelt, 2001). However, the move from deficit to dialogue (Wilsdon and Willis, 2004; Stilgoe and Wilsdon, 2009) creates an attitudinal barrier between science and the public. The ideas, opinions and knowledge of the public level become further disempowered and oppressed as the hierarchical divide between the practice level of science and the public still exists in the public understanding of science paradigm (Funtowicz, 2006; Stirling, 2008).

2.3.3 Science-and-Society Paradigm

Science-and-society emanated in the 1990s as science attempted to eliminate the paternalistic, top-down hierarchical approach to science communication and open the process to a 'new mood for dialogue' (Gregory and Miller, 1998; Davies, 2008; Miller, Fahy and the ESConet Team, 2009). The science-and-society paradigm is more commonly referred to as the public engagement with science era in the literature (Van der Sanden and Meijman, 2008; Bauer, 2009; Kurath and Gisler, 2009). The paradigm is more interactive in the way of a citizen-push approach in promoting science (Bora, 2005).

Poliakoff and Webb (2007) delineate engagement as any scientific communication that engages an audience outside of academia. A more expansive definition offered by Powell and Colin (2008, p.128) defines engagement as "interactive and iterative processes of deliberation among citizens and between citizens and government officials with the purpose of contributing meaningfully to specific public policy decisions in a transparent and accountable way". The avocation for engagement in science-and-society is viewed as more authentic and ethical than dialogue by Stoker and Tusinki (2006) as engagement is appreciative of difference (Trench, 2008).

The impetus towards engagement is expressed by Glicken (1999); Burningham et al. (2007) and Delgado, Kjolberg and Wickson (2011) in the literature. Public engagement is encouraged for instrumental, substantive and normative motivations (Delgado, Kjolberg and Wickson, 2011) which lead to better decision making, reduced conflict, greater legitimacy, the sharing of ownership and improved democracy (Glicken, 1999; Burningham et al., 2007). Jackson, Barbagallo and Haste (2005) further the democracy position, positing that engagement promotes open and transparent decision making. Science engagement systems open up the dialogue portal between the science community and the science attentive, science interested and the residual public (Pardo and Calvo, 2002). Kurath and Gisler (2009, p.559) postulate that in less than twenty years, “the style of science conversation with society has changed from the patronising tones of public understanding to the warmer banter of dialogue. Now it is changing again, to a more honest and reflective mode of listening and exchange”.

Miller, Fahy and the ESConet Team (2009) propose two fundamental limitations to public engagement. Firstly, “there has been little, if anything, in the usual training programme for working scientists that prepares them for such activities, and other pressures – demands to carry out research, to publish, and to seek grant funding – have left little time for extra training activities” (Miller, Fahy and the ESConet Team, 2009, p.117). In addition Delgado, Kjolberg and Wickson (2011) determine that public engagement is not the solution; in fact it is now the problem in science communication as the perceived knowledge and attitudinal deficits of the public are overridden by the trust and expert deficits with science.

2.3.3.1 Science-and-Society Deficit Model

Bauer, Allum and Miller (2007) in parallel with the thinking of Bauer (2009) postulate that the deficit model which appears in the literacy and understanding paradigms is reversed in the science-and-society literature. The authors advocate that the deficit model is no longer with the public, but with the science community who have lost the trust of the public (Kurath and Gisler, 2009). The crisis of trust in the science-and-society paradigm is highlighted by authors such as Sturgis and Allum

(2004); Rowe, Poortinga and Pidgeon (2006); Bauer, Allum and Miller (2007); and Powell and Kleinman (2008).

Gregory and Miller (1998, p.100) claim "it is a lack of trust rather than a lack of understanding, that leads to fear of science and that increasing understanding is just as likely to lead to more fear as to less". Gregory and Miller (1998) also posit that when the public trusts science, they pay it civil inattention. According to Gregory and Miller (1998, p.102) the public feel that they do not need to continually engage with science "but when the trust breaks down – when science seems to have gone wrong somehow – the civil inattention goes too, and suddenly the public are extremely interested to know and understand science". The crisis of trust between the science community and the public is extended further if the public connect science discourse with the involvement of the government (Lujan and Todt, 2007). Public distrust can escalate when the culmination of funding for science is being provided by governmental institutions and scientists rely on the policy level for future fiscal support (Lujan and Todt, 2007).

Wilsdon and Willis (2004) maintain that the advent of public engagement with science attempts to overcome the relational barrier of trust by deploying meaningful processes of engagement between science-and-society. Bauer, Allum and Miller (2007) also fortify the need for science to rebuild public trust through upstream public engagement. While science-and-society attempted to eradicate the consequential outcomes of didactic monologue and informal learning of the literacy and public understanding paradigms, it incurred the unexpected reversal of the deficit model to now lay blame at the door of science.

In summary, science-and-society opens up a new mood for dialogue which emphasises public engagement (Bauer, 2009; Miller, Fahy and the ESConet Team, 2009). However, engagement created a new deficit model which now affects science as opposed to the preceding deficits residing with the public. Trench (2008) maintains an ideological approach to science communication is to acknowledge the presence of the public and expert deficits, and to engage policy, practice and public levels in communication, not in an effort to change the levels or even change science, but because as human beings, we value our relationships with other human beings (Stoker and Tusinki, 2006). The next section furthers the value concept of relationships identified in the science-and-society paradigm by Trench (2008). Relationships underpin the science-in-society paradigm, with participation guiding the communication processes between the science community and the public.

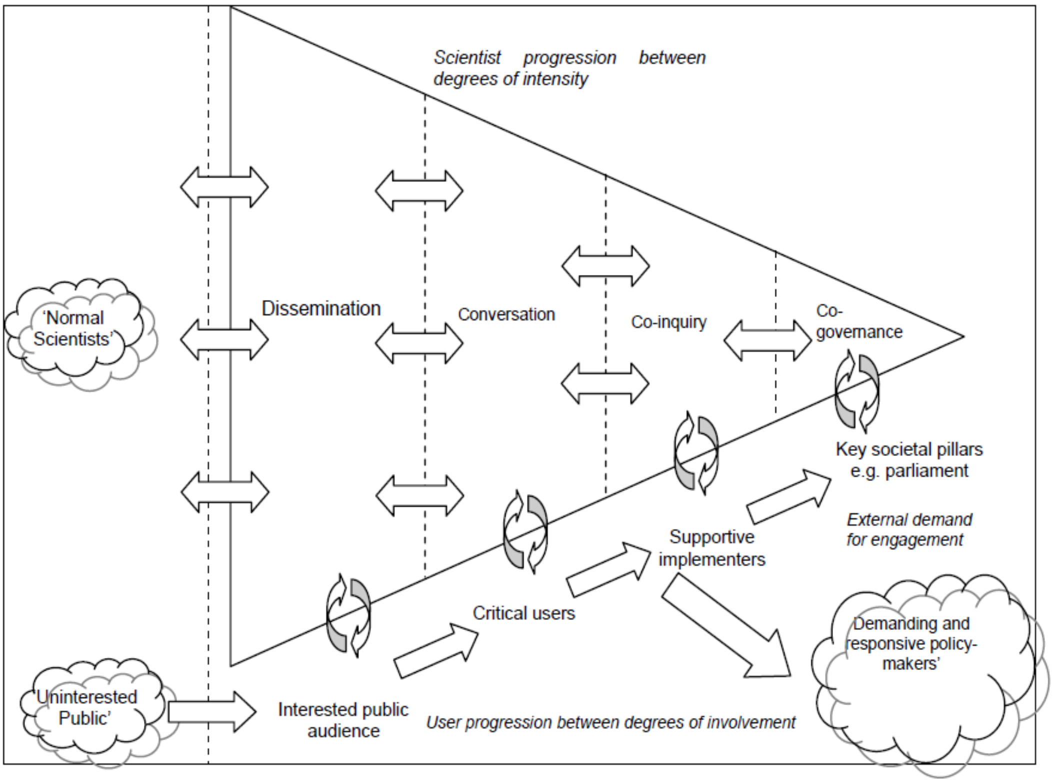
2.3.4 Science-in-Society

The European Commission (2009) observes how the role of science-in-society is under re-contextualisation, as there are more stakeholders involved in the process and the roles of both the science community and the public have diverged into expansive communication and participation. Stirling (2006, p.9) maintains that societies need to "move away from the somewhat fragmented introspective and reactive preoccupations of science 'and' society to a more integrated, open and proactive understanding of the inescapable place of science 'in' society". The paradigm of science-and-society assumed a "distinction between science and society and then attempted to bridge the gap. But phrased this way it was a self-constructed gap. On the one hand, there are certain differences between science and society and other systems of action, interaction and communication in society, but science is not outside society" (European Commission, 2009, p.9). The delineation of science-and-society reinforces an authoritive and autocratic stance to science communication (McGuire and Olson, 1996; Swyngedouw, 2000), where the model is closed to external influence and opinion.

Stirling (2006) necessitates the emergence of science-in-society, where the levels of policy, practice and the public integrate fact driven data and value laden judgements through open exchanges of knowledge co-production (Jackson, Barbagallo and Haste, 2005; Pulzl and Rametsteiner, 2009; Pallett, 2012), Science-in-society as contextualised by Stirling (2006) maintains that science should be informed by, and should therefore incorporate more effective forms of symmetrical two-way deliberation, empowering inputs from a wider diversity of science communication levels.

The Science for All Expert Group (2010, p.2) envisage that "those involved in the sciences listen to, engage with and are informed by knowledge, and views from the public, leading to increased learning and mutual respect between scientists, the wider society and policy makers". Society is now responding to economic pressures, as well as cultural and social changes through the recognition that policy makers without access to sound scientific advice, or to dialogue with communities, will be unable to make the best decisions on tough challenges facing the economy (European Commission, 2009). Science-in-society takes a systems approach to engagement, as illustrated in Figure 2.3.4, as each of the science communication levels co-frame, co-inquire and co-govern the communication and exchange processes.

Figure 2.3.4 The Systems Approach to Science-in-Society



Source: Benneworth (2009, p.5)

The systems approach to science-in-society embraces multi-directional and multi-dimensional exchanges in a web of interconnected relationships between the science community and the public (Roberts, 2011). Logan (2001, p.136) supports a participatory systems approach as the author suggests that "the flow of science knowledge is not always from experts to laypersons; it might be more shared or multi-directional". Bora (2005) maintains that the ideologies of the practice and policy levels need to change in the science-in-society paradigm. Science communication needs to embrace multiple stakeholders and multiple frameworks and to not just teach, but also learn, get involved, develop broader skills and build bridges to the public (Bora, 2005).

The participatory systems approach to science-in-society emphasises processes of exchange and processes of communication between the three levels of science communication. Science communication is no longer bound by the unilateral dissemination of scientific information from experts to the laypersons, but now contends with multiple exchanges for curiously driven science-for-science which aims to understand the world, and issue driven science-for-action which aims to solve societal problems (Van der Hove, 2007).

2.3.5 Summary of Science Communication Paradigms

The science communication paradigms of literacy, public understanding and science-and-society created three fundamental deficits. Knowledge and attitudinal deficits manifested at the public level while trust and expert deficits emerged with the science community. The science communication paradigms have shifted their communicational models from education and dialogue to engagement and participation. Participation in science communication recognises the emerging role of issue driven science which looks towards solving societal problems, and the science community are oriented towards action and change (Van der Hove, 2007). Science-for-action is inhibited by the theoretical gaps in science communication. These gaps are the source of discussion in the next section.

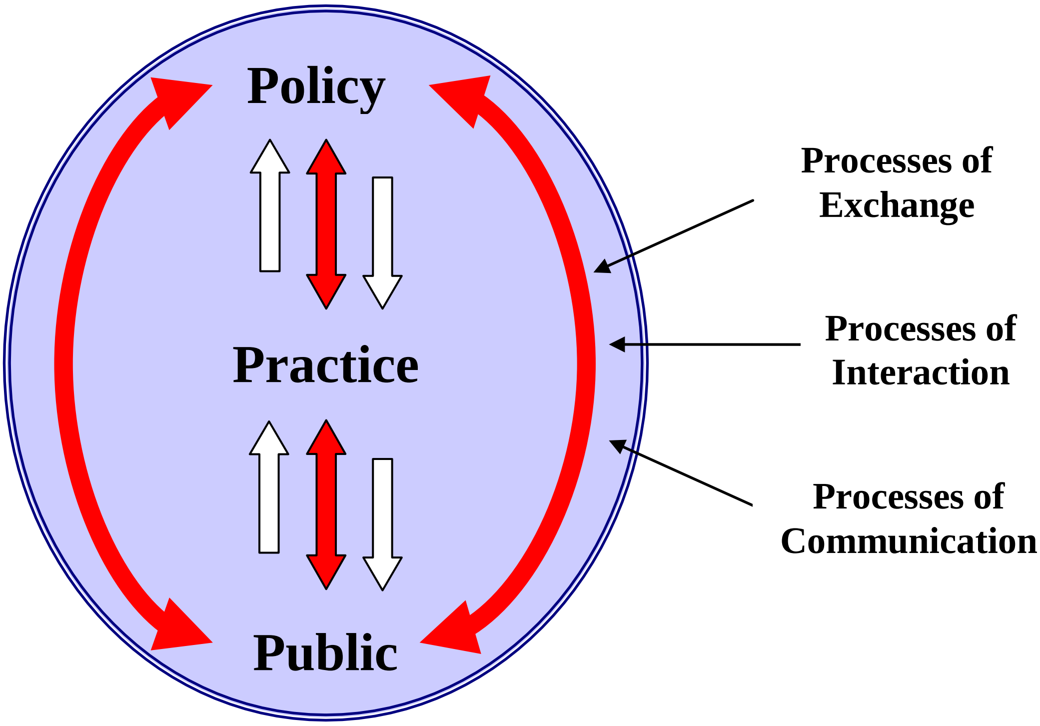
2.4 Theoretical Gaps in Science Communication

The preceding discussions depicted the levels, interface models and paradigms of science communication with a view to illustrating how science has progressed from informing models of communication to mutual participation. The following section identifies the theoretical gaps in science communication. Firstly, the deficit models are outlined. Secondly, the effects of the deficit models on the levels of science communication depict the theoretical gaps in the science communication literature.

According to Bauer (2009), four major components to the deficit model have emerged throughout the discussion on science communication paradigms: a public knowledge deficit in science literacy; a public attitude deficit in the public understanding of science; and the co-existence of trust and expert deficits in science-and-society.

Burns, O’Connor and Stocklmayer (2003), Sturgis and Allum (2004) and Besley and Tanner (2011) provide an alternative to the deficit model which is the contextual model. Burns, O’Connor and Stocklmayer (2003) perpetuate that a contextual model explores the interaction between science and its publics. Besley and Tanner (2011) also contend that a contextual approach gives non-experts a voice in science communication. The framing of the deficit model is asymmetrical in that it portrays science communication as a one-way, top-down flow of knowledge from the sufficiently knowledgeable scientist to the public who are deficient in their comprehension of scientific facts (Kim, 2007). Alternative to the deficit model is the materialisation of a symmetrical contextual model, which explores the interaction between science and society (Burns, O’Connor and Stocklmayer, 2003; Sturgis and Allum, 2004; Kim, 2007). The contextual model is appropriate to the science-in-society paradigm as it emphasises the need for multiple processes of exchange, interaction and communication between the policy, practice and public levels, as depicted in Figure 2.4.

Figure 2.4 Processes in Science Communication



Adapted from: Glicken (1999); Weigold (2001); and Lujan and Todt (2007)

The theoretical gaps in the science communication literature reside with these participatory processes of exchange, interaction and communication. As Van der Hove and Sharman (2006) highlighted in the science-policy interfaces and Trench (2008) highlighted in the paradigm section, there should be less concern over an evolutionary understanding of science communication, and an acknowledgement of the co-existent capabilities between policy, practice and the public levels. Van der Hove and Sharman (2006) propose there should not be an either/or choice between the interface models and paradigms, rather a participatory understanding of the information-transmission, dialogue and participatory approaches to science communication. Stirling (2008) argues that science communication dedicates a disproportionate amount of writing to the stylised understandings of participation and does not analyse the underlying processes which guide the communication of science. A combined analytical understanding of the information, dialogue and participatory processes in science communication, remains rudimentary in nature and have not been expanded or empirically tested.

2.5 Bridging the Gaps in Science Communication through Indicator Research

As the preceding section suggests, there is little formative evidence concerning the combined measurement of information, dialogue and participatory processes in science communication. The aim of this section is to elaborate upon the usefulness of indicator measurement in bridging the theoretical gaps from science communication. This section begins with a discussion on indicator measurement and the need for enhanced indicators in science communication.

The measurement of science and science policy through indicators is not new, as economic and social indicators emerged over half a century ago (Godin, 2001). The need for measurement in science has become increasingly important at all levels, from international policies at a supra macro level, to domestic policy at the macro level, right down to an organisational unit at the micro level. Sirilli (1999) contends that the basic challenge is not only looking at the past, but our ability to interpret the available indicators in order to learn lessons in view of future developments. Sirilli (1999, p.440) suggests that indicators are "therefore a sort of bell ringing, or a sign that has to be interpreted to make a forecast".

Indicators, as previously determined in chapter one are "statistical time series that measure changes in significant aspects of society" (Godin, 2001, p.5). Godin (2001) proffers three distinguishing features of an indicator. Firstly, indicators are warnings about change (Godin, 2001). Indicators provide invaluable evidence to policy makers, decision makers, regulators and institutions on the inputs and outputs of specific work practices, as indicators can "determine and monitor a trend which may be either positive, negative or unchanged" (City of Onkaparingo, 2000, p.11). Godin's (2001) second feature is that indicators are statistics that must be recurrent; otherwise they would not meet the measurement of change. Thirdly, indicators usually appear as a collection of statistics rather than a lone statistic, as a lone statistic can rarely be a reliable indicator (Godin, 2001). Similarly, Pencheon (2008) supports the collective aspect to indicators as the author views indicators as succinct measures that aim to describe as much as possible about a system. Therefore, in addition to measuring change, indicators also have the capacity to measure systems and their component parts.

Indicator measurement in science communication therefore becomes highly appropriate, as indicators measure changes to the processes of exchange, interaction and communication, whilst also measuring the system of science communication which incorporates the process activities between policy, practice and public levels.

Traditionally, frameworks such as the Frascati Manual (Freeman and Soete, 2009); the Oslo Manual (Smith, 2000 and Blankley, 2009); the Community Innovation Survey and its major data source of the European Innovation Scorecard (Blankley, 2009); and the Blue Sky Indicators Project have been committed to developing new science and technology indicators to better serve policy needs. However, these frameworks view science communication as a closed product with clearly defined inputs and output indicators, as opposed to viewing science communication as an open process where indicators measure the coordination and collaboration between policy, practice and public levels (Manzini, 2003). This limitation alongside other limitations of indicator measurement are outlined in the next section.

2.5.1 Limitations of Indicator Measurement

Coyle and Beth-Childs (2008) criticise the current research being conducted on process indicators as being ad hoc and yet to yield internationally comparable data and methodologies. Sirilli (1999, p.443) counter argues Coyle and Beth-Child's (2008) criticism as the author maintains that "indicator building is very demanding and time consuming and that the development of a new science indicator takes roughly ten years". Freeman and Soete (2009, p.584) argue that the "simple tabulation of expenditures on personnel and equipment inputs to research and development is by no means easy, and international comparisons are beset by numerous challenges". Furthermore, the measurement of outputs from the production system is even more difficult. Inputs and outputs are indispensable measures of scientific progress but they are becoming constricted as societies evolve and the social, political, cultural and organisational impacts of science (Godin and Dore, 2004) remain under-researcher and under-explored.

Gault (2007) alongside Blankley (2009), advocate for the construction and measurement of micro driven indicators. Indicator research is limited by its compulsion to measure macro data quantitatively (Gault, 2007). Furthermore, research is beginning to see the value of measuring both change and systems through qualitative and quantitative measures. Godin (2003, p.16) critiques the need for enhanced indicators as he concludes that “the knowledge-based economy is above all a label and that most, if not all indicators collected are indicators that the OECD had already been measuring for years … or are variations on old indicators that had suddenly become subsumed under the concept of the knowledge-based economy”.

Another limitation hampering indicator measurement is the lack of evidence relating to the activities, impacts and linkages of science (Ertl et al., 2007; Gault, 2007; Godin, 2009). Activity, impact and linkage indicators are important for illustrating how “various parts of the economy and society are interconnected” (Ertl et al., 2007, p.102). There is no doubt that limitations exist within the indicator measurement literature. Gault (2007) and Blankley (2009) articulate that the progress of indicator measurement now requires a dialogue process between the producers and users of indicators. Sirilli (1999, p.441) summated most succinctly that “the limitations and shortcomings of science and technology models must not, however be considered an insurmountable obstacle to the devising and application of a set of indicators. On the contrary, they should be considered a natural part of a knowledge-developing process that has already yielded significant results” though the generations.

2.5.2 The Need for Enhanced Indicators in Science Communication

Current indicator frameworks measure science as a product rather than a process which omits the measurement of societal change and a systems orientation (Manzini, 2003). There are several activists at the frontier of indicator enhancement, namely Smith (2000); Godin (2001; 2002); Godin and Dore (2004); Ertl et al. (2006) and Pencheon (2008). Indicators currently serve a pluralistic role of monitoring and evaluation in science (Ertl et al., 2007; Pencheon, 2008). Monitoring and evaluation show how important indicators are to all sectors, and all levels of society. Every stakeholder and level affected by change, albeit consciously or unconsciously, is affected by the measurement of science.

Smith (2000) alongside Godin and Dore (2004) suggest that the emergence of interactive models of knowledge production require enhanced indicators in science. Knowledge in science communication is currently co-exchanged and co-produced between the policy, practice and policy levels. Godin and Dore (2004) synthesise that the majority of measures for the impact of science are concerned with economic impacts. The measurement of system impacts are almost totally absent from the literature.

Godin and Dore (2004) argue that indicators need to be enhanced to measure the multi-dimensionality of science. Science communication incorporates multiple stakeholders from multiple sectors and levels throughout the processes of interaction, exchange and communication. Milbergs and Vonortas (2004) mobilise further the multi-dimensionality aspect to science as the authors highlight the non-linear style to science communication. The "non-linearity of science requires an expanded series of real time metrics reflecting the new paradigm of a knowledge-based networked economy to guide innovation policies and illuminate the uncertainties, choices and outcomes of government policy and business decisions" (Milbergs and Vonortas, 2004, p.3).

The interactive, multi-dimensional and non-linear orientations of science reflect the need for enhanced indicators as a way of capturing the dynamics of change (Coyle and Beth-Childs, 2008). Lepori, Barre and Filliatreau (2008, p.34) operationalise that "the size of the science and technology systems have greatly increased; linkages and complementarities between science and technology actors now co-exist; and the spatial organisation of the system has become complex". The multi-dimensional and non-linear orientations of science can be best captured in a new generation of indicators for science communication.

2.5.3 A New Generation of Indicators

Enhanced indicators for science communication acknowledge that the integration of macro data with micro data is more valuable to an economy than macro data alone (Gault, 2007; Blankley, 2009). Micro data relating to activities and linkages are an area in the indicator literature which theorists and analysts believe is of utmost importance to the development of new and improved indicator sets (Ertl et al., 2007; Gault, 2007 and Blankley, 2009). As far as the literature and indeed this study is concerned, there is value in capturing indicators external to the macro realm. Micro and in particular, meso level data on activity and linkage indicators capture the coordination and exchange of resources as well as illustrating how actors are connected to other social or economic organisations and institutions (Rose and McNiven, 2007). The limits of existing literature in capturing and explaining micro level data is noticeable among authors such as Milbergs and Vonortas (2004); Stone et al. (2008) and Rose et al. (2009) who advocate a new fourth generation of process indicators for science, which is conveyed in Table 2.5.3.

Table 2.5.3 Evolution of Indicators by Generation

1st Generation Input Indicators *(1950s-60s)*	**2nd Generation Output Indicators** *(1970s – 80s)*	**3rd Generation Innovation Indicators** *(1990s)*	**4th Generation Process Indicators** *(2000 + emerging focus)*
• R&D expenditures • S&T personnel • Capital • Tech intensity	• Patents • Publications • Products • Quality change	• Innovation surveys • Indexing • Benchmarking innovation capacity	• Knowledge • Intangibles • Networks • Demand • Clusters • Management techniques • Risk/Return • System dynamics

Sources: Milbergs and Vonortas (2004); Stone et al. (2008); Rose et al. (2009)

The fourth generation of process indicators are "grounded in a knowledge-based networked economy, remain ad hoc and are the subjects of measurement" (Rose et al., 2009, p.5). Generation one to three reflect the unidimensionality and linearity of science at the macro level of society, where indicators of measurement have been based on agreed and validated numeric metrics related to economic functions (Godin and Dore, 2004; Milbergs and Vonortas, 2004). Alternatively, the fourth generation of process indicators highlight the non-linearity of science (Milbergs and Vonortas, 2004); where quantitative aggregate statistics will no longer suffice as measurement tools. Dodgson and Hinze (2000, p.102) suggest that measuring processes in its entirety as “a combination of activities that are highly complex, socially embedded and idiosyncratic is impracticable. Instead the measurements of the elements that stipulate and shape the processes are considered, rather than the process itself”. Manzini (2003) supports the need for a process emphasis in science communication as the author highlights that processes open the door to public participation. Processes in science communication emanate from the integration of the policy, practice and public levels as well as the extended participation interface model and the science-in-society paradigm.

Process indicators can bridge the theoretical gaps in science communication. Process indicators mobilise the analytic understanding of the participatory processes of exchange, interaction and communication within and between the policy, practice and public levels of science communication. However, it is difficult for science communication to conceptualise the process indicators, as the field has no prior empirical research relating to participatory processes. Reflecting on the scarcity of empirical research concerning processes and participation, this study integrates the literature area of science communication with social marketing and innovation in order to fully comprehend holistic participation processes and conceptualise process indicators for science communication. This integration of literatures is extensively developed in the next chapter.

2.6 Chapter Summary

Science communication is a complex process (Manzini, 2003). The literature acknowledges science communication as a process; however, analysts have concentrated on science communication as a static and evolutionary process as opposed to a dynamic and inter-related process of mutually interconnected interfaces and paradigms (Trench, 2008). Science communication; to affect progressive change and the need the move upstream (Wilsdon and Willis, 2004) must move beyond the theoretical gaps of the recurring deficit model and concentrate on the integrative understanding of both open and closed participatory processes in science communication (Stirling, 2008). This chapter identifies the need for enhanced indicators in science communication. Process indicators can provide effective measurements of the elements that stipulate and shape processes in science communication (Dodgson and Hinze, 2000). However, the lack of empirical research relating to processes in science communication hampers the development of measurable process indicators.

The next chapter outlines how an interdisciplinary approach to science communication, through its integration with social marketing and innovation theory, provides a better understanding of holistic participation processes and the subsequent development of process indicators for science communication.

Chapter Three: The Integration of Science Communication with Social Marketing and Innovation

3.0 Introduction

Social marketing and innovation theory assist science communication in developing a holistic understanding of participation and process indicators. Social marketing emphasises processes that influence, shape and bring about change not only at an individual level, but collectively, at community, societal and public policy levels (Lefebvre, 2012). The level plurality in social marketing endears a total market approach to change where the focus resides with participatory processes in the marketplace, rather than with the individual (Lefebvre, 2011). Innovation also embodies a participatory approach as interactive processes between macro, meso and micro environmental levels create economic and social value (Lundvall, 2007). When analysed together, social marketing and innovation theory permeate the boundaries between the policy, practice and public levels in science communication to co-produce participative change.

The objective of this chapter is to examine how social marketing and innovation theory extend the analytic understanding of participatory processes in science communication. The purpose of understanding participation through the lens of social marketing and innovation theory is to develop and measure process indicators for science communication, as the measurement of these indicators underpins this study's primary research question and secondary research objectives. Social marketing, through a total market lens and innovation theory, through a multi-dimensional view, have the ability to progress science communication beyond collective action where knowledge is co-produced, to open social learning, where policy makers, practitioners and the public co-learn and co-facilitate the process of participation (Roberts, 2004).

A full outline of the themes discussed within this chapter is presented in Figure 3.0.

This chapter begins with the identification of social marketing as a total market approach.

Figure 3.0 Overview of Chapter Three

3.0 Introduction

3.1 Social Marketing: A Total Market Approach

- From Transactional to Complex Exchange
- From Individual to Population Based Behaviour Change
- Social Ecology Theory

3.2 A Total Market Approach to Science Communication

- Communication and Dialogue
- Interaction
- Value
- Value Co-Creation
- A Summary of Social Marketing and Science Communication

3.3 Innovation: A Multi-Dimensional View

- Levels of Innovation
- From the Resource Based View to the Relational View

3.4 From Closed to Open Networks in Science Communication

- Interorganisational Networks
- Network Characteristics
- Co-Innovation
- A Summary of Innovation and Science Communication

3.5 Developing Process Indicators for Science Communication

- Knowledge
- Networks
- Intangibles
- System Dynamics
- Summary of Process Indicators

3.6 Chapter Summary

3.1 Social Marketing: A Total Market Approach

Social marketing is a conceptual framework which applies marketing concepts and techniques to co-create value for individuals and society (Gordon et al., 2006; Lefebvre, 2012). Historically, social marketing operated at the downstream level selling brotherhood like soap (Wiebe, 1951). As social marketing progressed, the emphasis moved upstream (Andreasen, 2006) towards societal change. At present, social marketing analyses behaviour, value and exchange through top-down, bottom-up and interactive processes, co-creating a total market approach to behavioural and societal change (Russell-Bennett, Previte and Zainuddin, 2009; French, et al., 2010; Hoek and Jones, 2011; Lefebvre, 2011).

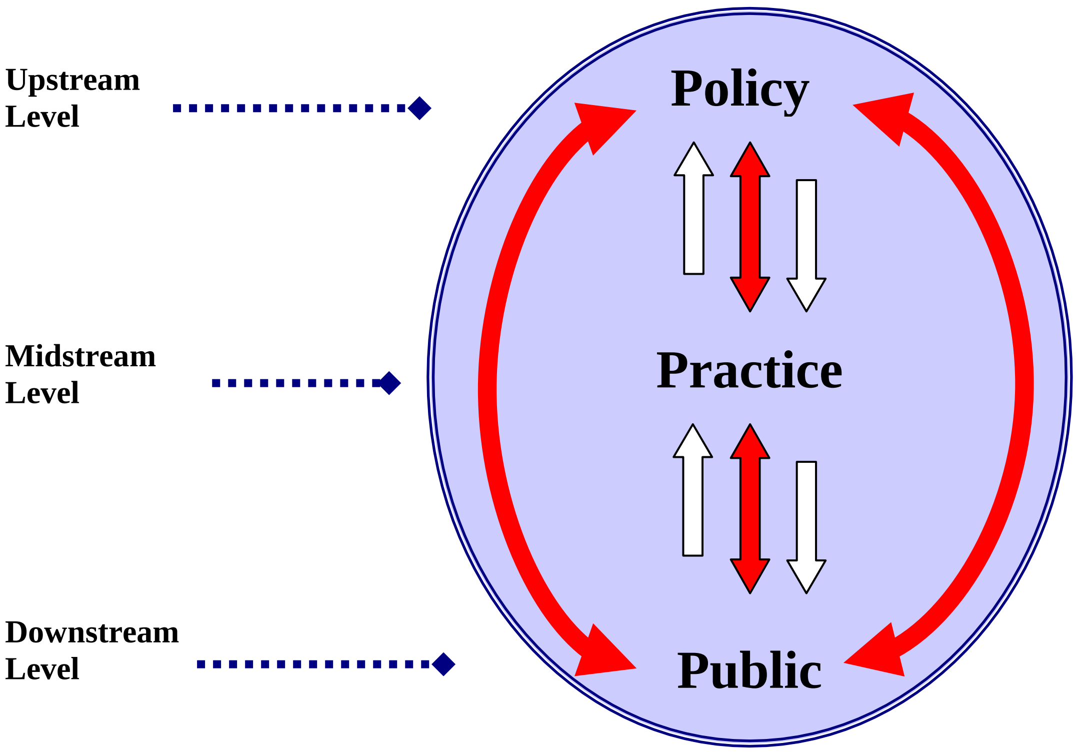
Social marketing, as previously outlined in chapter one:

> *"Develops and applies marketing concepts and techniques to create value for individuals and society. This is done through the integration of research, evidence-based practice and the use of social-behavioural theory together with the insights from individuals, influencers and stakeholders. These inputs and perspectives are used to design more effective, efficient, sustainable and equitable approaches to enhance social well-being. The approach is one that encompasses all the processes and outcomes that influence and are associated with change among: individuals, organisations, social networks and social norms, communities, businesses, markets, and public policy" (Lefebvre, 2012, p.120).*

Lefebvre (2012) depicts social marketing as a transformative process where multiple insights from multiple levels and layers of influence, affects change. Social marketing mobilises three interconnected levels of influence, referred to as up, mid and downstream levels (Goldberg, 1995; Gordon et al., 2006).

Upstream levels of influence in social marketing reflect the macro level of society (Domegan, 2008). Government, policy makers, legislators and key decision makers constitute the upstream level that controls the social context (Domegan, 2008). These stakeholders catalyse large-scale systemic change by changing the environments within which the individual operates (Goldberg, 1995; Crutchfield and McLeod-Grant, 2008). The upstream level of social marketing incorporates the policy level of science communication, as illustrated in Figure 3.1, where distal forces determine the historical and societal factors that form the science communication policy system (Cullen, Sullivan and Junge, 2007).

Figure 3.1 Integrating Social Marketing with the Levels of Science Communication



Adapted from: Glicken (1999); Weigold (2001); and Lujan and Todt (2007)

Midstream social marketing efforts reflect the group or organisational level where practitioners operate in science communication. Social marketing at the midstream level emphasises interorganisational relationships between practitioners and the policy and public levels through community-based social marketing (McKenzie-Mohr and Smith, 1999; Domegan, 2008). Community-based social marketing acts as a complimentary process to the distal forces of science communication (Cullen, Sullivan and Junge, 2007), as the midstream level determines the proximal forces that shape and influence science communication, such as the rules and procedures governing an activity; the practitioners involved and the expected outcomes (Cullen, Sullivan and Junge, 2007).

Downstream social marketing shapes and influences change at the micro level of the individual. Social marketing has been very effective in changing individual behaviour (Wymer, 2011) in areas such as public heath and the environment. However, the recursive procrastination of individual behaviour change can result in victim blaming (Hoek and Jones, 2011), as social marketing programmes repeatedly focus on the downstream individuals who are carrying out bad behaviour (Andreasen, 2006). Historically, downstream social marketing used pervasive educational efforts, social advertising and social communication to inform and curtail the behaviour of individuals (Lefebvre and Flora, 1988; Smith, 2002). Likewise, downstream science communication efforts adopted information-transmission styles of communication to produce change. Science communicators now appreciate that they have to move beyond didactic and transactional approaches of public education, to much preferred downstream approaches of participating with the public (O' Shaughnessy, 1996; Mitsuishi, Kato and Nakamura, 2001; Davies, 2008).

Andreasen (2006) perpetuates that there should not be an attack between downstream or upstream solutions, rather than an appreciation of both forms. Hoek and Jones (2011) support the viewpoint of Andreasen (2006) by placing upstream and downstream social marketing efforts on a horizontal continuum which enables an integrative approach to social change. Alternatively, Goldberg (1995) perpetuates that outcomes determine the decision between downstream and upstream social marketing approaches. Downstream social marketing emphasises equilibration as any change to a system is relatively minor and within the scope of individual action (Goldberg, 1995). Upstream social marketing creates change from "broad collective or institutional solutions" (Goldberg, 1995, p.365) where there is institutional or societal change. Goldberg (1995), like Andreasen (2006) and Hoek and Jones (2011) views upstream and downstream social marketing processes as complimentary and even interactive. However, Dholakia (1984) argues that change takes place for society as a whole and only an upstream macro level approach can examine the effects of social marketing as well as the processes of social marketing.

Science communication has been particularly salient at achieving upstream macro level societal change. However, the empowerment of the individual voice in the participation process lacks rigorous understanding. Inzelt (2008) suggests that science communication needs to integrate the centralised top-down model with a society of networks and community of practices approach which emphasises multi-directional forms of dialogue. Multi-directional and multi-dimensional interactions between up, mid and downstream stakeholders in science communication reflects a total market approach to social change.

Total market approaches from social marketing interconnect vertical and horizontal forms of coordination and integration in science communication (French and Blair-Stevens, 2010b). Vertical coordination emphasises how communication flows bi-directionally *through* the policy, practice and public levels (Crutchfield and McLeod-Grant, 2008). Horizontal integration emphasises exchanges between stakeholders *within* each of the three levels in science communication. The collaborative integration of vertical and horizontal coordination processes mobilises participation *with* and *through* others to create more impact than the levels could ever achieve alone (Crutchfield and McLeod-Grant, 2008). Total market approaches to science communication move us beyond a “sole focus on the parts, referred to as reductionism, and instead shift our analysis to an alignment of interconnected parts linked together in a web of relationships” (Roberts, 2011, p.677). Furthermore, a total market approach can bridge and even coalesce (Lefebvre, 2011), the gaps between policy, practice and the public in science communication.

The attainment of a total market approach to science communication incorporates two core benchmark criteria of social marketing; exchange and behaviour (French and Blair-Stevens, 2010a). Science communication exchanges are progressing from utilitarian forms of quid-pro-quo to complex relational exchanges between policy, practice and public stakeholders (Bagozzi, 1975). The complexity of exchange in science communication is subsequently reflected in participatory behavioural patterns as stakeholders embellish top-down, bottom-up and integrative coordination efforts (Bronfenbrenner, 1977).

The preceding discussion interlinked up, mid and downstream levels in social marketing through a total market approach. The next section examines the core benchmark concepts of social marketing; exchange and behaviour, assessing the complex relational exchanges and multi-faceted participatory processes in science communication.

3.1.1 From Transactional to Complex Exchanges

Exchange is a key characteristic of social marketing (Hastings, 2007; French and Blair-Stevens, 2010). In its purest form, exchange involves a transfer of something tangible or intangible, actual or symbolic, between two or more social actors (Houston and Gasseinheimer, 1987). Exchange takes a plurality of forms, including once off dyadic transactions, once off triadic transactions, dyadic exchange relationships and triadic exchange relationships. Bagozzi (1975) in addition to Houston and Gasseinheimer (1987) determine that exchange transactions, albeit dyads or triads, involve the simple quid pro rationale of pure economic exchange whereby goods are exchanged for money. Bagozzi (1975, p.38) counter argued Houston and Gassenheimer's (1987) transactional orientation stating that exchange is not the simple quid pro quo notion characteristic of most economic exchanges. Rather social marketing relationships exhibit what may be called generalised or complex exchanges. Social marketing emphasises mutually beneficial exchange relationships where each of the parties involved benefits from a win-win situation as opposed to a win-lose situation (Marques and Domegan, 2011; Hastings and Domegan, in press). Luck (1974, p.71) in opposition to Hastings (2007) and French and Blair-Stevens (2010) contests the validity of exchange in social marketing, stating that a "person who receives a free service is not a buyer and has conducted no exchange of values with the provider of the service".

The movement from exchange transactions to complex exchange relationships can be analysed through Bagozzi's (1975) framework where the author distinguishes between the types and meanings of exchange.

3.1.1.1 Exchange Types

Bagozzi (1975), one of the most accredited authors on exchange theory, predicates that there are three types of exchange, each evident in science communication. First, restricted exchange occurs between two actors in the form of a dyadic and bidirectional transaction. Each actor gives and receives during the exchange transaction, reflecting the central economic principle of quid pro quo, whereby each actor gives something of value for something of value (Bagozzi, 1975). Hastings and Domegan (in press) uphold the bidirectional impetus of exchange as the authors ascertain that exchange only occurs, if both parties to the exchange transaction increase mutual utility. Science communication, in the literacy paradigm incurred restricted exchange transactions in the form of education. However, exchange resembled a monologue of expertise being transmitted from the expert to the laity (Dornan, 1990; Kurath and Gisler, 2009), with little to no bidirectional interaction between the levels, omitting Hastings and Domegan’s (in press) perspective of reciprocal and mutually beneficial exchanges.

Second, generalised exchange denotes univocal reciprocal relationships among at least three actors in the exchange situation (Bagozzi, 1975). The actors do not directly benefit from each other; rather they are integrated into a system of indirect benefits and reciprocity. Glenane-Antoniadis et al. (2003) reaffirm the plurality of generalised exchange as the authors denote its responsibility to a system of mutual relationships. The public understanding of science epoch emphasises the mutuality of dialogue between the levels in science communication, as policy makers and practitioners assess what the public want to know about science (Borchelt, 2001). Science communicators make extensive use of listening and learning strategies to facilitate the mutuality of dialogical exchanges between policy makers, practitioners and the public (Burgess and Clark, 2006; Hastings and Domegan, in press).

Finally, complex exchange enlarges the system perspective as exchange refers to a system of mutual relationships between at least three parties (Bagozzi, 1975; Juttner and Wehrli, 1994). Glenane-Antoniadis et al. (2003) suggest that complex exchanges are different to generalised exchanges in that the exchange process is reciprocal and it has an extended time frame. Furthermore, exchange transactions have developed into the formation of exchange relationships as there is now an impetus towards a long-term orientation in exchange. Buchanan, Reddy and Hossain (1994) maintain there is little consensus towards mutuality in complex exchange as contributors are motivated by self-interested goals and manipulation. According to Buchanan, Reddy and Hossain (1994), exchange, in spite of its good intention, engenders win-lose orientations as the practice and policy levels are consumed by the need to give the public the benefit of their wisdom. For science-and-society and science-in-society, complex exchanges extract the direct proposition of quid pro quo from the restricted exchange perspective, amalgamating it with the indirect benefits of the generalised exchange perspective, reflecting a system of interdependence and a web of interconnecting relationships (Roberts, 2011).

Exchanges in science communication are complex, as the exchanges involve multiple stakeholders from multiple levels informing, listening, learning and exchanging ideas and views with one another (Burgess and Clark, 2006). The complexity surrounding the exchange process involves the elimination of hierarchical power and mutual antagonism (Buchanan, Reddy and Hossain, 1994) which are inherent in closed sequences of exchange (Bagozzi, 1975). Dann (2008) suggests that complex exchanges instead occur through open network structures, whereby series of smaller participatory exchanges in science communication offer value to policy, practice and public levels, and the benefits flow throughout the system in the form of interconnected relationships. Science communication can create a better functioning society when complex exchanges embrace interconnectivity, reciprocity and mutuality between the policy, practice and public levels (Hastings and Domegan, in press), rather than delineating exchange to be a self fulfilled prophecy of individualistic behaviour (Bagozzi, 1975).

Bagozzi’s (1975) restricted, generalised and complex exchanges are evident in each of the science communication paradigms. As science communication moves towards a participatory orientation, the meaning of exchange becomes extremely important to the public level as it determines the motivations of the participatory exchange process (Hastings and Domegan, in press).

3.1.1.2 The Meaning of Exchange

The meaning of exchange captures the reasons behind the exchange or the explanation of its occurrence in science communication, which Bagozzi (1975) categorises into three levels: utilitarian, symbolic and mixed exchange. Utilitarian exchange is built on the foundation of economics, whereby the goods are given in return for other goods or money (Bagozzi, 1975; Juttner and Wehrli, 1994). Juttner and Wehrli (1994) argue that utilitarian exchange reflects self-interested behaviour as individuals' proportion their dedication to the exchange process by the added value they receive from other parties. Science communication in the embryonic paradigm of science literacy mirrored utilitarian exchange, as policy makers needed to enhance the literacy of citizens to attract foreign direct investment (Hilliard and Green, 2004). Policy makers believed that the provision of education would result in more knowledge and in turn more knowledge would increase interest and careers in the sciences (Gregory and Miller, 1998). Upstream levels in science communication exalted self-interested behaviour (Juttner and Wehrli, 1994) which inversely affected the exchange process as recipients "attitudes that were based on knowledge – whether positive or negative – were held more strongly and thus resisted change" (Bauer, 2009, p.224).

Symbolic exchange explains the occurrence of exchanges by transfer of psychological, social or other intangible values (Juttner and Wehrli, 1994). Symbolic exchange focuses on natural input and learning as the focus subsides from the value of the object to the meaning of the process, and the importance of continuous exchange relationships. The public understanding of science era reflects symbolic exchange as bi-directional dialogues were opened between policy, practice and public levels, where each listens as much as talks (Goncalves, 2006).

Mixed exchange integrates both utilitarian and symbolic aspects of exchange (Bagozzi, 1975). According to Juttner and Wehrli (1994, p.59) the "generated value can therefore reflect tangible or intangible attributes of the products and/or intangible aspects of the process". Mixed exchange defends the proposition that exchange is a process where actors accurately proportion the relinquishment of their self-interested goals to the fulfilment of mutual interests and collective value. Mixed exchange processes are complex by nature, as exchanges operate within a complex web of interactions and interdependencies between policy, practice and public levels in a wider area of value creation (Henneberg, Mouzas and Naude, 2006). Mutuality and collectivity form the central thrust of mixed exchange in science communication as both science and society want to contribute to, and learn from the processes of exchange, interaction and communication between the multiple levels to facilitate issue driven science-for-action (Van der Hove, 2007).

3.1.1.3 Complex Exchange Processes

Traditional science communication paradigms uphold and reinforce the utilitarian perspective of restricted exchange, as policy makers and practitioners engaged in forms of communication and promotion that derived from the neoclassical rhetoric of a quid pro quo perspective (Bagozzi, 1975). Science communication must move beyond the tenets of restricted exchange, to a much preferred approach of social exchange (Ivens and Blois, 2004). Social exchange transcends closed sequences of restricted antagonism (Bagozzi, 1975; Buchanan, Reddy and Hossain, 1994) where self-interests prevail in the deficit models, to the adoption of a collective total market approach where policy makers, practitioners and the public interconnect to facilitate relational exchanges through extended participation (McKee and Wang 2006). Participation amplifies the importance of generalised and complex exchange as the social marketing exchange processes are embedded in the dense fabrics of social relations (Bagozzi, 1975; Easton and Araujo, 1994).

The context of social relations must be defined within the overall context of exchange to determine who the actors are, the interactions they will embrace and the transfer of tangible or intangible, actual or symbolic resources in science communication processes (Anderson, Challagalla and McFarland, 1999). Smith (2002) elaborates on the process of exchange necessary to shape the publics' participation. Smith (2002) contends that the public will engage in participatory processes if they value them (Smith, 2002). Therefore, it is critical for policy makers and practitioners to understand what the public wants to know and find ways of making that knowledge available and accessible (Borchelt, 2001). Participatory processes in science communication, like social marketing become entrenched in the exchange of social issues, ideas and behaviours as opposed to tangible products (Peattie and Peattie, 2003).

Collective and relational exchanges in science communication are complex and evasive as the orientations shift from short term transactions to the complex formation of value systems (Juttner and Wehrli, 1994). The value system design of social marketing exchange is extremely pertinent to the area of science communication, as it comprises of a system of interdependent actors from policy, practice and public levels who raise the total value of the system through interactive value-generating processes and compete with other systems of action of which they are parts (Juttner and Wehrli, 1994). Participation in science communication is reliant upon the complex exchange process, as upstream levels actively seek public participation.

Hastings and Saren (2003) maintain that complex social marketing exchanges have met three levels of resistance which relate to the ambiguity surrounding the benefits of exchange; that those who instigate exchange may be seeking to benefit from the transaction and lastly, resistance can accumulate regarding the prerequisites and the balance of power in the exchange process. Hastings and Saren's (2003) three levels of resistance are also reflected in the issues of motivation and compromise set out by Hastings and Domegan (in press). Furthermore, French (2009) accentuates the compromise issue in exchange in terms of money, time, effort and social consequences. Compromise is particularly prominent in science communication exchanges as the publics' participation and involvement with science communication depends on a fundamental shift in behaviour at practice and policy levels. Williams and Kumanyika (2002) maintain that a change in mindset is necessary where individuals are embedded in a recurrent behaviour that requires change. Policy and practice levels in science communication are indoctrinated by deficit models which create hierarchical boundaries with the public. To realise a collective exchange relationship, policy and practice levels need to move towards the reduction of autocratic and linear exchanges with the public. The empowerment of the public level through multi-directional exchanges facilitates participation, reciprocity, interconnectivity and mutual learning in society

To summate, science communication paradigms at present uphold and reinforce the utilitarian perspective of restricted exchange which derives from the neoclassical rhetoric of a quid pro quo perspective (Bagozzi, 1975). Science communication must move beyond the tenets of restricted exchange, to a total market approach of social exchange (Ivens and Blois, 2004). Total market social exchanges necessitate a change in mindset and behaviour from authoritarian deficit models to multi-directional and multi-dimensional exchanges in science communication. Participatory processes in science communication, like social marketing are entrenched in the exchange of social issues, ideas and behaviours as opposed to tangible products (Peattie and Peattie, 2003). The next section illustrates how social marketing can facilitate a total market approach to change in science communication.

3.1.2 From Individual to Population Based Behaviour Change

Individual-based behaviour change incorporates downstream social marketing efforts where individuals are responsible for the modification of their behaviour (Goldberg, 1995). Lefebvre (2000) critiques social marketers for dedicating a disproportionate amount of attention to individual theories of change. In response to Lefebvre (2000), authors such as Andreasen (2006); Hoek and Jones (2011); Kennedy and Parsons (2012) and Hastings and Domegan (in press) realise the value of moving beyond individual-based behavioural change strategies to population and societal based change. Population-based behaviour change analyses change at the institutional and societal levels where the whole is greater than the sum of the parts (Langlois, 1983) and processes underpin the complex exchange of issues, ideas and behaviours in social marketing (Peattie and Peattie, 2003).

Glasgow and Emmons (2007) acknowledge that although there has been increased movement towards population-based interventions, these interventions address each component of society as if it were an independent intervention. Costanza et al. (1993) also advocate Glasgow and Emmons' (2007) viewpoint as the authors contend that population-based behavioural change should analyse behaviour from a holistic orientation, but its applications employ reductionistic methods where the behavioural system analyses interconnected parts. The use of reductionistic methods to analyse complex population-based behaviour change does not work.

Reductionistic system methods should only be utilised to understand system structures and individual-based behavioural change (Costanza et al., 1993). Consequently, Glasgow and Emmons (2007) argue for greater attention for connectedness across interventions, programme levels, components and systems.

Social Ecology Theory advanced by Urie Bronfenbrenner acknowledges the connectedness of population-based behavioural change and constitutes the theoretical framework which guides the understanding of a total market approach to social marketing and science communication. The next section will examine Social Ecology Theory and discuss its effectiveness in participatory processes between policy, practice and public levels in science communication.

3.1.3 Social Ecology Theory as the Theoretical Framework for Science Communication

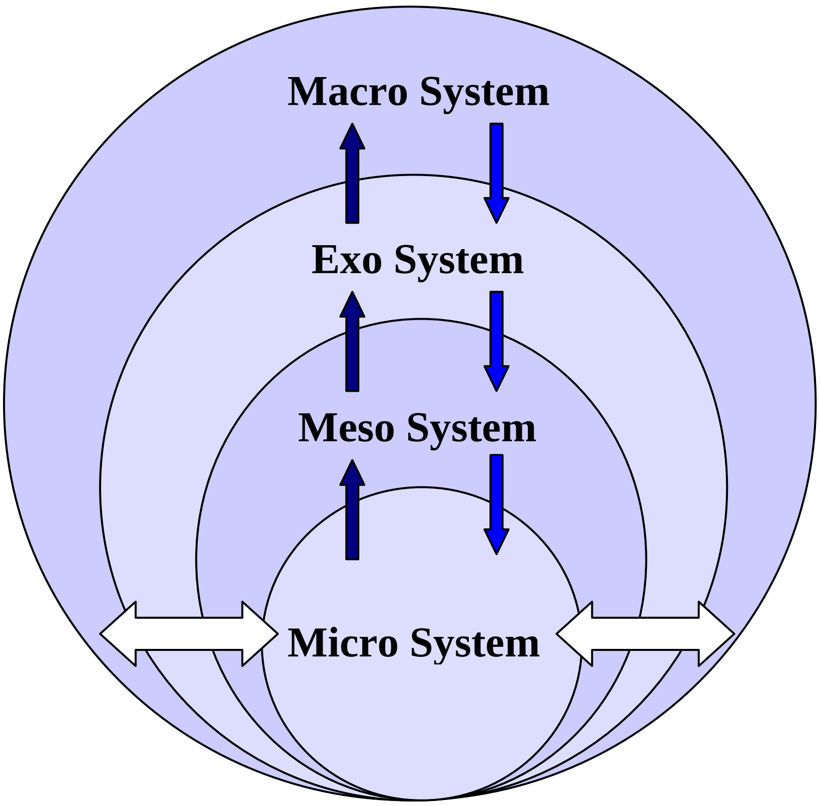
Social Ecological Theory (SET) widens the perspective on change as the theory analyses behaviour at the systems level (Hastings and Domegan, in press). SET is concerned with behavioural and environmental influences, and assesses the role of public policy in behaviour change (Maibach, 2002). SET, as opposed to individual-based behaviour change models takes into account the publics' interaction with their physical and sociocultural surroundings (Sallis et al., 2006). Rather than positing that behaviour can be micro managed through the efforts of individuals (Goldberg, 1995), SET analyses behavioural influences at multiple levels in a system (Dresler-Hawke and Veer, 2006; Sallis et al., 2006).

Baranowski et al. (2003) recognise the importance of multiple levels to SET, but also appreciate that SET is much more challenging than individual-based behavioural change strategies. SET integrates multi-level, multi-structural, multi-factorial, and multi-institutional influences within a behavioural system and coordinates the cross level interrelationships among these influences (Hastings and Domegan, in press). Lomnicki (1992, p.4) contends that the analyses and coordination of pluralistic behaviours is complex because "we try to predict how the entire system behaves".

All too often, behavioural change strategies in science communication have attempted to understand the parts of a system through reductionistic methods, whereby the public's behaviour is reduced into rationally manageable components. Reductionism in science communication represents restricted exchanges where upstream policy makers and practitioners attempt to understand the behaviour of the public without any consultation. McCay (1978) argues that in systems ecology, individual behaviour is no longer an independent function and science communication should embrace relational exchanges where multi-dimensional behaviour is accepted and understood (Hastings and Domegan, in press).

The defining feature of SET are the layers of behavioural influence that take into account the physical environment and its relationship to people at individual, intrapersonal, institutional, community and public policy levels (McLeroy et al., 1988; Morgan and Hunt, 1994). SET integrates four broad levels or systems; microsystems, mesosystems, exosystems and macrosystems (Bronfenbrenner, 1979) which interconnect with the levels of science communication.

Figure 3.1.3 System Levels in Social Ecology Theory



Adapted from: Sallis, Owen and Fisher (2008)

The microsystem consists of the general public, science interested and science attentive (Pardo and Calvo, 2002). The mesosystem represents the organisational or institutional factors that shape or structure the environment, within which the individual operates (Goldberg, 1995). Scientists, the media, science educators and science communicators are actively involved at the meso level. The exosystem refers to community level influences represented by well established norms, standards and social networks (Gregson et al., 2001). The macrosystem differs in a fundamental way from the previous system in that it comprises of the cultural contexts as well as the physical environment. SET, as a population-based behavioural strategy emphasises reciprocal causation where the public both influence, and are influenced, by those around them (Story, Neumark-Sztainer and French, 2002; Rimer and Glanz, 2005).

Lefebvre (2000) states that behavioural change interventions are either contained to the individual micro system, or the societal macro system, with little to no systems integration. Glasgow and Emmons (2007) also highlight that it is rare to adopt behavioural intervention strategies beyond one level. Reidenbach and Oliva (1983) suggest the containment of behaviour change to one level exhibits a closed system, where interaction is limited to who the policy and practice levels choose to involve (Burgess and Clark, 2006). Closed ecological systems embrace linearity, where policy makers in the hierarchical macro system communicate the desired behaviours ‘to’ the subordinate downstream practice and public levels (Lusch, Vargo and O’Brien, 2007). These linear and rudimentary mechanisms of exchange inhibit the flow of ideas, information and knowledge within and across the multiple levels of science communication (Jaworski, Kohli and Sahay, 2000). Furthermore, these closed and confined exchanges exhibit a first order relationship in that the stakeholders involved in science communication are functionally necessary to one another (Lewis and Erickson, 1969).

Alternatively, SET perpetuates an open system of change where interaction is likely to occur, bidirectionally and multi-directionally between policy makers, practitioners and the public. The open coordination of systems in SET is especially appropriate to science communication and the movement towards participation, as SET emphasises top-down, bottom-up and interactive effects between the micro, meso, exo and macro systems. These effects are also aligned to the up, mid and downstream levels of social marketing (Domegan, 2008). The coordination of top-down, bottom-up and interactive effects empowers communities and societies as well as the individual (Dresler-Hawk and Veer, 2006). The empowerment of the individual in participatory processes is lacking in science communication. The absence of individual empowerment is advocated by Bora (2005, p.1) who calls for an ecological approach to science communication where "the simple linear model of explaining science to the public is replaced by a complex, systemic, multi-directional, and multi-level concept. This concept is more interactive in the way of a citizen-push approach promoting innovation with and for everyone".

Reidenbach and Oliva (1983, p.10) suggest that marketing is an "open system, while for all intents and purposes the environment is a closed system". Likewise, science communication are open systems as the structures, actors, institutions and concepts of participation are in place, but the processes to ensure top-down, bottom-up and interactive effects are absent, closing the system to coordinated and interactive linkages between policy makers, practitioners and the public (Hastings and Domegan, in press).

In summary, behaviours do not occur in a vacuum. SET adopts a wider perspective to change than individual-based behavioural strategies as the whole network behaviour model addresses multiple levels of behaviour influence (Hastings and Domegan, in press). Coordination and interaction across and between the macro, meso, exo and micro levels of influence empowers the voice of society and the public throughout exchange, reflecting a total market approach to science communication.

Exchange and behaviour are critical to the understanding of participatory processes in science communication. Exchange analyses the complexity surrounding the need for relational exchanges between policy, practice and public levels in science communication. Exchange also facilitates the divergence from restricted, utilitarian styles of exchange in science communication to the embeddedness of mutually beneficial relationships between stakeholders (Bagozzi, 1975; Hastings and

Domegan, in press). The shift in mindset towards relational exchange also necessitates a shift in behaviour beyond a short term focus. SET affords science communication the opportunity to coordinate multi-structural, multi-factorial and multi-institutional influences and exchanges between policy makers, practitioners and the public. Social marketing, in addition to exchange and behaviour, offers a marketplace perspective for how inefficiencies in science communication can be addressed and how the dynamics can be shifted to better serve the needs of the public, practitioners and policy makers in society (Lefebvre, 2012).

The next social marketing section will further the total market approach to science communication by discussing the pillars of relational exchange processes which include, communication and dialogue; interaction; value and value co-creation. This discussion deepens the understanding of participatory processes within and across the levels of science communication.

3.2 A Total Market Approach to Science Communication

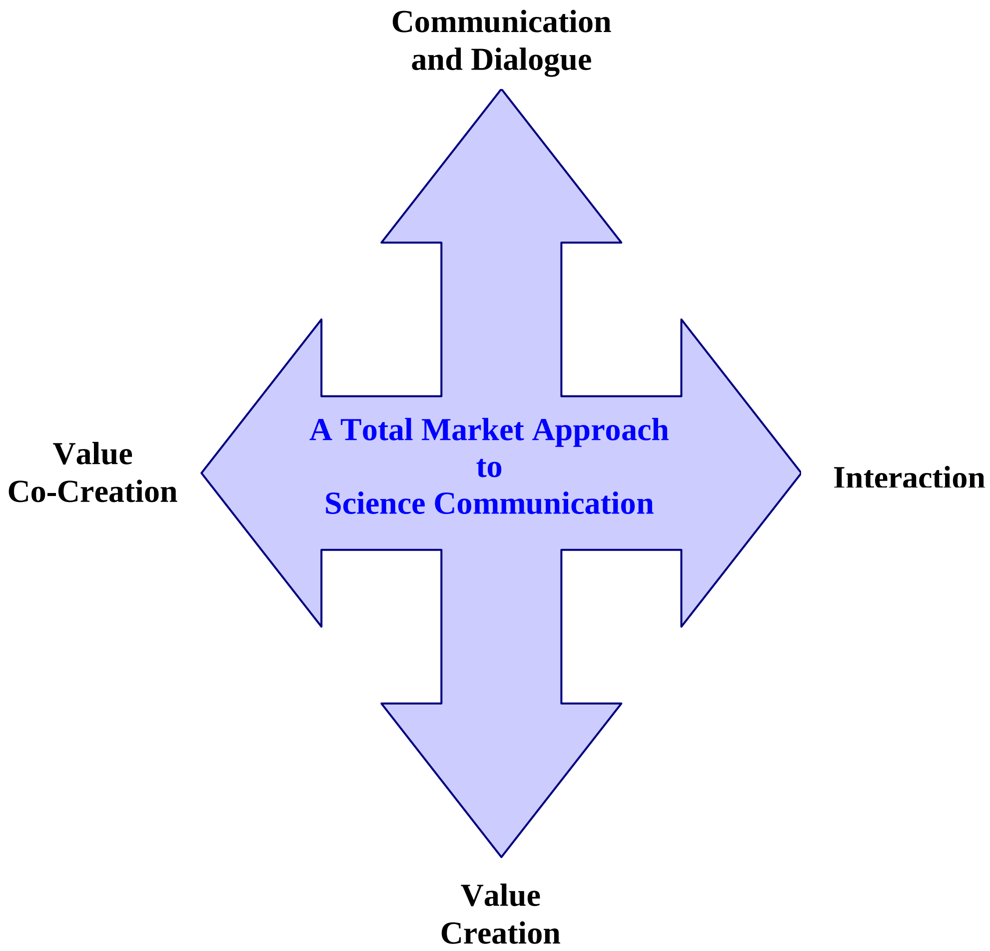
Science communication has reached a crossroads where policy makers and practitioners see the value of empowering and engaging the public in science deliberation processes. The move towards participation has been difficult as upstream stakeholders revert to traditional linear methods of one-way communication with the public (Burns, O'Connor and Stocklmayer, 2003). Policy makers and practitioners have become accustomed to telling the public how to behave for the betterment of society (Russell-Bennett, Previte and Zainuddin, 2009).

However, it is not sufficient to gauge public views and opinions at the end of a deliberation process when their inputs do not project change. Instead, Russell-Bennett, Previte and Zainuddin (2009, p.215) suggest that if upstream levels such as policy and practice "seek to affect social change they need to understand how value is created and how it changes" throughout the entire deliberation process.

A total market approach to science communication is a continuous value-generating process where the inter-related levels are perceived as a nested and interconnected arrangement of structures (Bronfenbrenner, 1978). The interconnectivity between levels is depicted through the top-down, bottom-up and integrative exchanges between policy makers, practitioners and the public. McGuire and Olson (1996) advocate that policy and practice levels to facilitate interconnectivity, should assume horizontal positions in the system of science communication, as opposed to authoritive and coercive roles in a vertical hierarchical system. Horizontal relationships shift the exchange relationship from conflict to neutral cooperation, choice independence and mutual interdependence (Goldberg, 1995). Reinforcing this perspective, Lusch and Webster (2010) contend that traditional, hierarchical and bureaucratic organisational forms, guided by command and control have become increasingly obsolete. In response, Cova, Prevot and Spencer (2010) argue that inter-organisational exchanges are more likely to occur when systems deconstruct hierarchical modes of governance.

At present, hierarchical modes of governance separate the upstream levels of policy and practice from the downstream level of the public. SET demonstrates the ability of science communication to embrace complex exchanges through collaboration and interconnectivity within and across the multiple levels. SET also facilitates feedback loops and the realignment of science communication levels with wider societal values (Hastings and Domegan, in press). SET coordinates a total market approach to science communication, as it transcends the co-production of knowledge between levels to the facilitation of co-learning (Roberts, 2004). Roberts (2004) argues that solutions to complex societal issues are not givens; they are discovered through co-learning processes. Co-learning in science communication is “nurtured through dialogue – enabling participants to respect and listen to one another’s opinions, and through deliberation – enabling competing perspectives to be aired and considered before decisions are made” (Roberts, 2004, p.330). Roberts (2004) as well as Russell-Bennett, Previte and Zainuddin (2009) and Hastings and Domegan (in press) advocate that the public are no longer passive recipients of knowledge. Effective participation necessitates the empowerment of the public in science communication where co-creation becomes an important consideration in addition to interaction, dialogue, communication and value creation (Roberts, 2004; Russell-Bennett, Previte and Zainuddin, 2009; Hastings and Domegan, in press). A total market approach emphasises interaction processes, communication processes and value processes (Gronroos, 2004), as illustrated in Figure 3.2. The remainder of this section will discuss these four participatory processes for science communication.

Figure 3.2 A Total Market Approach to Science Communication



3.2.1 Communication and Dialogue

Communication and dialogue are central to science communication, as chapter two highlighted. There are two facets to communication in science. First, literacy and the publics' understanding of science are consumed by hierarchical processes of top-down unidirectional communication, in which the flow of information streams from the experts down to the lay public (Dornan, 1990; McGuire and Olson, 1996). The distinction between experts and lay persons alongside the notion of illiteracy placed immense pressure on the need for a new mode of communication in science.

Upstream science communicators understand the benefits of two-way communication, but fail to grasp that a two-way process is associated with trust as an open dialogue process (Hastings and Domegan, in press). French and Blair-Stevens (2010) assimilate two-way processes as the integration of vertical and horizontal communication. The transition towards integrative communication styles in social marketing depicts equality amongst stakeholders in the exchange process. Social marketing integrates communication from the bottom-up and the top-down in one holistic system of multi-directional and multi-dimensional communication. A holistic approach to science communication will benefit both the upstream policy and practice levels and the downstream public level of science communication, as equality empowers each level in their roles as advocates, consumers, volunteers, co-producers and co-learners (Roberts, 2004).

Furthermore, equality in social marketing is depicted by Hastings and Domegan (in press) who suggest that resource integrators can pool their valuable resources together and operate collectively through two-way dialogue processes. Lusch, Vargo and Tanniru (2010) contend that a shift from propaganda towards conversation and dialogue accentuates the joint creation of knowledge between up, mid and downstream levels of society, to ensure communication exchanges are reciprocal (Russell-Bennett, Previte and Zainuddin, 2009). Two-way communication eliminates the monologue tendencies of policy makers and practitioners in science, and replaces it with a dialogical process with the public (Ballantyne and Varey, 2006). The facilitation of open dialogue between the science community and the public exemplifies how practitioners are transitioning from the ownership of scientific knowledge to the creation of dialogical portals with the public (Funtowicz, 2006). Ballantyne and Varey (2006) augment the concept of dialogue from an extended conversation to an interactive process of learning. Dialogue facilitates participation through the empowerment of the passive public who jointly co-determine experiences, outcomes and benefits for society (Russell-Bennett, Previte and Zainuddin, 2009). Dialogical relationships shape societal interaction (Hastings and Domegan, in press) and these interactions according to Ballantyne and Varey (2006) are built on trust. Trust is present in communication when both partners share similar values and their relationship is not characterised by one partner dominating the dialogical process (Hunt and Morgan, 1994). Trust is inextricably linked throughout communication processes (Hunt and Morgan, 1994).

Trust is also critical to science communication processes. As chapter two revealed, science communication is burdened by the recurrent crises of trust between upstream and downstream levels (Bauer, Allum and Miller, 2007). Morgan and Hunt (1994) suggest that trust, as an antecedent to relationship formation and development, gives rise to productive and effective relational exchanges. Moreover, trust between the levels of science communication preserves equality as it instils confidence in each resource integrator to contribute their inputs and knowledge to the communication process. Two-way dialogical processes in science communication are inherently dependent on collaborative interaction between policy makers, practitioners and the public.

3.2.2 Interaction

Russell-Bennett, Previte and Zainuddin (2009) suggest that experiential approaches in social marketing include value from the interaction itself as well as outcomes. Zainuddin, Russell-Bennett and Previte (2007) emphasise dyadic interactions in social marketing. Dyadic interactions are dynamic, active and collaborative processes that can be instigated by either party in a relationship and can be maintained and strengthened over time (Hastings and Domegan, in press). Ballantyne (2004) mobilises the perspective that dialogue becomes nested within interaction leading to the emergence of dialogical interaction (Ballantyne and Varey 2006). Dialogical interaction is not unidirectional, self-serving, or accomplished by control. On the contrary, the purpose is open-ended; discovery orientated, and value creating (Ballantyne and Varey, 2006). Dialogical interaction facilities the interactive process between scientists and the public as it capitalises upon the collective co-production of knowledge within and across the whole system of science (Pallett, 2012). Roberts (2011) asserts that dialogical interaction detaches each party from their habitual routines of generating individual silos of knowledge. Dialogical interaction emphasises equal collaboration in a system instead of hierarchical ownership (Roberts, 2011). Ballantyne and Varey's (2006) major contention is that interaction facilitates the co-production of knowledge, which is essential in science communication as it integrates the insights, inputs and ideas of the stakeholders from policy, practice and public levels rather than the elite experts (Kurath and Gisler, 2009). Dialogical interaction emphasises the multi-directional and multi-dimensional sharing of experiential knowledge in science communication which adds value to the relationship process. Interaction between the levels in science communication has a direct influence on value creation and value co-creation (Zainuddin, Russell-Bennett and Previte, 2007).

3.2.3 Value Creation

A unique aspect of social marketing is that it expands the value propositions offered to individuals and society (Lefebvre, 2012). Value according to Tzokas and Saren (1997, p.111) can be defined as "a relativistic preference characterising a subject's experience of interacting with some object". According to Russell-Bennett, Previte and Zainuddin (2009) there are two approaches to value in the social marketing: economic and experiential. Economic value focuses on the utility gained throughout the exchange process. The emphasis on utilities reflects the proponents of restricted exchange (Bagozzi, 1975) where individuals seek the attainment of their own self-interested goals (Juttner and Wehrli, 1994). Alternatively, experiential value approaches are interactive and relativistic experiences (Russell-Bennett, Previte and Zainuddin, 2009). Experiential values reflect complex collective systems where relational exchanges between the up, mid and downstream levels are integrated to create joint value for individuals and society (Lefebvre, 2012; Hastings and Domegan, in press).

Roberts (2004) argues that in the pursuit of co-production, individualism and self-interests are valued. Furthermore, Roberts (2004) advocates that facts and values are not intertwined throughout the process of co-production. Likewise, in science communication, the interfaces between the science community and policy demarcate clear boundaries between facts and values (Pulzl and Rametsteiner, 2009), eliminating value choices (Roberts, 2004). Lefebvre (2011) argues that values overlap in social marketing. Roberts (2004, p.341) produces a view which resonates well with science communication as the author comments that "the values are there, the strategies are there, the people are there. It is simply up to all of us to make it happen". Science communication understands that the boundaries between levels as well as the boundaries between facts and values must be blurred (Pulzl and Rametsteiner, 2009). The blurring of boundaries creates greater value for science communication as policy and practice levels integrate with the public (Hoek and Jones, 2011).

Zainuddin, Russell-Bennett and Previte (2007, p.125) argue that it is "necessary to focus on the central role of interactivity within the exchange process where value creation occurs". Value creation is a consequential outcome of inter-related processes of collaboration and interaction between up, mid and downstream levels in social marketing. Value creation processes deviate from value-in-exchange to value-in-use (Vargo and Lusch, 2008; Vargo, Maglio and Archpru-Akaka, 2008).Value-in-exchange epitomises restricted and economic exchange processes where each party to the exchange process increases their individual utility (Russell-Bennett, Previte and Zainuddin, 2009). Value-in-use reflects a generalised exchange image, whereby experiential value is created through the interactions between stakeholders (Woodruff and Flint, 2006).

Hastings and Domegan (in press) maintain that up, mid and downstream relationships established in value exchanges prosper through the joint creation of value. Intra-sectoral and cross-sectoral partnerships create more value than self-interested economic motivations (Lefebvre, 2012). Consequently, science communication can create value through meaningful exchanges and the co-production of experiential value between policy, practice and public levels.

Communication, dialogue, interaction and value are integrated and interwoven in one overarching process of relationship building in social marketing. Palmer (1996) advises that relational exchanges have incurred limitations in the forms of asymmetrical and self-opportunistic behaviours. Relationship building and interaction prove extremely difficult in science communication as policy makers, practitioners and the public at present, pursue self-interested goals. Science communication recognises the need to move beyond dyadic forms of interaction, communication and value to the materialisation of co-learning and value co-creation for science-in-society. Co-learning and the co-creation of value in science communication develops “citizen identity, builds learning communities, and harnesses the energy and talents of all members of a democratic society” (Roberts, 2004, p.330).

3.2.4 Value Co-Creation

Lefebvre (2012) suggests that the focus of social marketing becomes one of facilitating and supporting a process of value co-creation where people take on the roles of co-producers, collaborators, facilitators and co-learners (Roberts, 2004). Individuals at the downstream level are no longer objects for relationships, they are now subjects who voluntarily collaborate and participate in value co-creation (Desai, 2009). The co-creation of value gives a voice to the public that was previously non-existent in the literacy, public understanding of science and science-and-society paradigms. Co-creation unifies the public with the practice and policy levels in an open system of coordination which emphasises value-in-information (Sheth and Uslay, 2007). Value-in-information recognises that value cannot be created in isolation. Value-in-information collectively integrates the knowledge, insights and perspectives of multiple stakeholders from multiple levels, creating holistic and experiential knowledge for science communication as illustrated in Table 3.2.4.

Table 3.2.4 The Changing Contribution of Value to Science Communication

	Science Communication as Utility Creating and Value Adding	Science Communication as Public Oriented and Value Proposing	Science Communication as Public Unifying and Value Co-creating
Value Creation	Value Added	Co-Production	Co-Creation
Locus of Value	Value-in-exchange	Value-in-use	Value-in-context Value-in-information
Integration of Facts and Values	Separation of facts and values	Mixing of facts and values	Integration of facts and values
Primary Focus	Dissemination; Education	Dialogue	Conversation; Engagement
Boundaries between Levels	Boundaries well delineated	Boundaries blurring	Outside boundaries
Purpose of Interaction	Self-interested utility	Collective utility through self-interested motives	Collective utility
Key Concepts	Specialisation; Centralisation; Delegation;	Planning; Implementation; Control;	Sensing; Responding; Learning;

Adapted from: Bauer (2009); Pulzl and Rametsteiner (2009) Lusch and Webster (2010)

In the drive towards participation, value co-creation processes have the ability to transfer experiential knowledge across and between the levels in science communication (Ballantyne, 2004). Knowledge transfer embodies the top-down, bottom-up and interactive effects of SET, where the system of science communication is open and transparent (Prahalad and Venkat, 2004; Desai, 2009). Openness encourages the upstream levels to detach from their habitual routines of generating individual silos of knowledge and actively co-create that knowledge with the public (Desai, 2009). Co-created value-in-information gives a voice to the public that was previously ignored by policy makers and practitioners.

Vargo and Lusch (2010, p.182) maintain that "value is always co-created as it moves away from the linear sequential creation, flow and destruction of value towards the existence of a much more complex and dynamic system of actors that relationally co-create value". Vargo and Lusch (2010) create a dynamic interplay between exchange and value as the authors demonstrate how linear value flows resemble restricted exchange patterns. Linear value moves in a unilateral fashion from one stakeholder to another where the end objective is to add value and enhance the utility of the individuals. Complex value co-creation resonates with collective exchange, as exchanges are created with individuals and value is co-created for both individuals and society, setting the foundations for complex exchange relationships in social marketing (Lefebvre, 2012; Hastings and Domegan, in press). Science communication strives to integrate the values of the public with the values of practitioners and policy makers in an attempt to create a system of reciprocal and mutually beneficial relationships (Vargo, Maglio and Archpru-Akaka, 2008).

The concept of co-creation focuses on the bi-directional and multi-directional interactions that occur between groups (Zainuddin, Russell-Bennett and Previte, 2007). Roberts (2011) also advocates interconnected webs of value interactions. Interactive value processes satisfy mutual interests and facilitate co-learning, resulting in win-win situations for the exchange actors (Roberts, 2004). Value co-creation in science is complex and multi-dimensional, as it changes the roles of the public from being isolated, passive and unaware to strategically connected, active and informed (Prahalad and Venkat, 2004). Value co-creation processes absorb high levels of knowledge intensity which compels stakeholders to co-define, co-create and co-deliver value within and across the whole system, to ensure social change. Russell-Bennett, Previte and Zainuddin (2009) contend that co-creation becomes an important consideration for social change as it empowers both the individual and society. The combined empowerment of stakeholders at policy, practice and public levels can result in an integrative process of co-intelligence and co-learning for science communication (Roberts, 2004). Prahalad and Venkat (2004) alongside Desai (2009) argue that the facilitation of inter-system connectedness, trust and learning in value co-creation assists in the understanding of complex exchanges between up, mid and downstream levels in society.

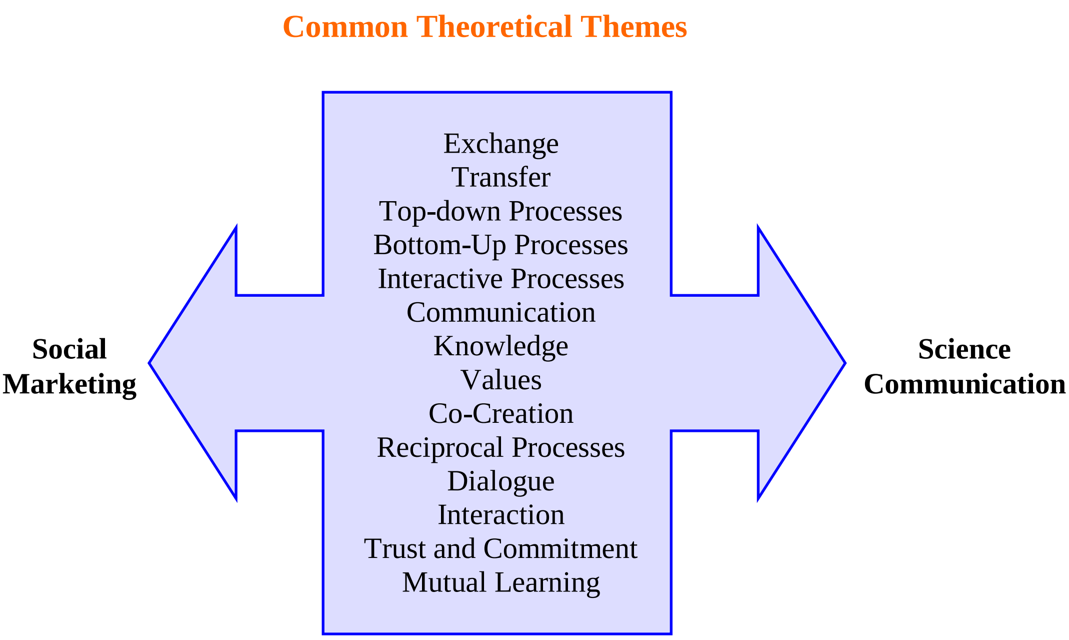
In science communication, value co-creation processes highlight the need to move away from closed systems of authoritarian governance to open systems of integrative empowerment. Long lasting behavioural change for science communication requires a total market approach led by government, and includes a wide range of stakeholders and organisations as well as the public themselves (Darnton, 2008). Total market approaches in science communication open up this opportunity for synergistic partnerships to co-create value and social learning (Roberts, 2004). Openness in science communication identifies collaborative links between levels through the establishment of inter-system relationships. Value co-creation plays a fundamental role in empowering the collaborative links between up, mid and downstream stakeholders in a dynamic and inter-related system of science communication.

3.2.5 A Summary of Social Marketing and Science Communication

Referring back to chapter two, science literacy, the public understanding of science, science-and-society and science-in-society paradigms depicted science communication matters as a tribal identity (Bauer, Allum and Miller, 2007). Each paradigm "frames the problems differently, poses characteristic questions, offers prepared solutions, and displays a rhetoric of progress over the previous one" (Bauer, Allum and Miller, 2007, p.79). Delgado, Kjolberg and Wickson (2011) argue that science communication is coming of age and the fallacious links associated with the evolution of deficit models must be severed in order to appreciate how science communication paradigms are porous and shifting towards an integrated participation (Bauer, Allum and Miller, 2007; Stirling, 2008; Trench, 2008, Pallett, 2012).

Social marketing, through a total market approach reflects participatory processes between up, mid and downstream levels of science communication. The common between social marketing and science communication are illustrated in Figure 3.2.5.

Figure 3.2.5 Common Theoretical Themes between Social Marketing and Science Communication



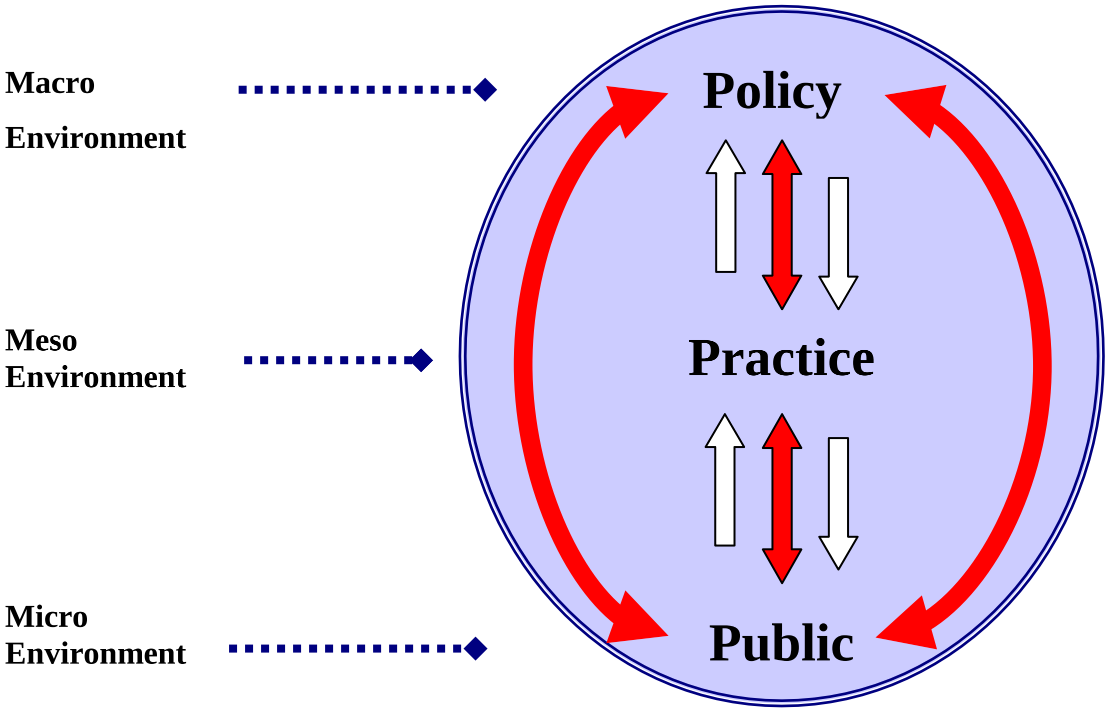
This chapter highlights how exchange and behaviour, as two benchmark criteria of social marketing provide a better understanding of participatory processes for science communication (French and Blair-Stevens, 2010a). In unison, social marketing's exchange and behavioural models epitomise a holistic model of participation between individuals and society (Lefebvre, 2012). Holistic participation captures the broader picture to science communication, focusing on the multiple structures, functions, processes and environments in which stakeholders engage (Reidenbach and Oliva, 1983; Hult and Ferrell, 1997). A total market approach adopts a societal mindset to participatory processes in science communication, emphasising the co-integration of top-down, bottom-up and interactive effects of participation.

In addition to the total market approach of Social Marketing, the multi-dimensional view of innovation also purports an enhanced understanding of participatory processes for science communication.

3.3 Innovation: A Multi-Dimensional View

Innovation, as previously defined in chapter one by the Council on Competitiveness (2005, p.8) concerns the *"intersection of invention and insight, leading to the creation of social and economic value"*. Innovation emphasises the economic value of invention and insight whilst also highlighting societal value, which underpins the processes of public participation in science communication. The integration of economic and societal values coordinates innovation into three interlinked levels comprising of the macro, meso and micro environments as illustrated in Figure 3.3.

Figure 3.3 Integrating Innovation with the Levels of Science Communication



Adapted from: Glicken (1999); Weigold (2001); and Lujan and Todt (2007)

The three interlinked levels of innovation share sharp similarities with the levels of science communication. The macro level of innovation concerns policy makers, regulators, advisory boards and agencies who are responsible for developing and measuring public policies, mirroring the policy level of science communication. Stone et al. (2008) alongside Rose et al. (2009) denote that the meso environment refers to the institutions and organisations that are responsible for creating economic value (Stone et al., 2008; Rose et al., 2009), resembling practitioners in science communication. The last level; the micro environment similar to that of the public level consists of individuals and collective groups of individuals within organisations, who generate, explore, share, integrate and exploit their skills, ideas and knowledge with other organisations. Consistent with the three levels of science communication, innovation looks to integrate ideas and knowledge within and across the macro, meso and micro environments through middle-up-down networks (Nonaka, 1994). This section through a multi-dimensional view of innovation emphasises the levels of innovation and the relational dimensions to innovation.

3.3.1 Levels of Innovation

Yang, Lin and Lin (2010) deconstruct the levels of innovation to three levels; internal, dyadic and networks. As innovation intersects with additional stakeholders, the focus moves beyond the internal boundaries of the individual to dyadic interactions with other organisations and extenuates to network levels where multiple stakeholders at multiple levels interact simultaneously (Yang, Lin and Lin, 2010). The gradual systems orientation of innovation adopts a broader view of coordination and collaboration processes, as interactions move across and between the macro, meso and micro environments.

Nooteboom (2000) offers a similar stratification to the levels of innovation as Yang, Lin and Lin (2010). Nooteboom (2000) contends that innovation occurs at multiple levels, such as within a team, in the firm, on the level of the industry or an entire economic system. Tidd and Bessant (2009) compress Nooteboom's (2000) levels of innovation into two categorisations; component or architectural. Component levels of innovation occur within an organisation or between organisations. An architectural level combines the component levels of innovation into one overarching structure (Tidd and Bessant, 2009). Prahalad and Krishnan (2008) compare the architecture level of Tidd and Bessant (2009) to a new house of innovation where "the social architecture – organisation structures, performance measurement, training, skills, and values of the organisation – must reflect the new competitive imperatives. So must the technical architecture of the firm – its information technology backbone" (Prahalad and Krishnan, 2008, p.6).

In spite of the varying terminology and stratifications of innovation, Nooteboom (2000); Prahalad and Krishnan (2008); Tidd and Bessant (2009) alongside Yang, Lin and Lin (2010) converge on the opinion that the levels of innovation are extremely important in the innovation literature. The levels of innovation purported by Yang, Lin and Lin (2010) and Nooteboom (2000) reflect the science communication paradigms of science literacy, the public understanding of science, science-and-society and science-in-society as innovative organisations move from a competitive orientation to a collaborative and relational orientation at the network level. Networks reflect the multi-dimensional nature to innovation where top-down, middle-up-down and bottom-up knowledge creation processes emerge between the macro, meso and micro environments (Nonaka, 1994).

The levels of innovation also encompass a triadic evolution to innovation as the views progressed from resource and institutional orientations to relationally based outlooks on innovation.

3.3.2 From the Resource Based View to the Relational View

As the preceding section illustrates, there is little consensus among the innovation theorists as to how to define the levels of innovation (Nooteboom, 2000; Prahalad and Krishnan, 2008; Tidd and Bessant, 2009; Yang, Lin and Lin, 2010). The converging assertion is that multiple levels of innovation co-exist. However, the multiple views (resource, institutional, relational) which drive invention and insight determine if innovation processes are closed to the internal level or open to dyadic and network level interactions.

3.3.2.1 The Resource Based View

Zaheer and Bell (2005) maintain that organisations at an internal level have the resources and capabilities to generate insights for innovation. The collective assimilations of insight within the boundaries of the firm proliferate into knowledge which in turn produces innovations (Zaheer and Bell, 2005). A resource based view motivates the internal level of an organisation to examine and exploit its internal resource characteristic – knowledge specialisation (Peteraf, 1993; Barney, 2001; Yang, Lin and Lin, 2010). The resource based view has been examined by several authors in the innovation domain such as Peteraf (1993); Barney (2001); Zaheer and Bell (2005); Mesquita, Anand and Brush (2008) and Lin, Yang, and Arya (2010), all of whom contend with the exact delineation of what constitutes knowledge. Accordingly, knowledge falls into two broad categories; explicit and tacit (Choi and Lee, 2002; Katsamakas, 2007). According to Katsamakas (2007, p.182) "explicit knowledge can be articulated and codified, while tacit knowledge cannot. Tacit knowledge has a personal and social quality and is deeply rooted in action, commitment and involvement in a specific context. It has a cognitive element – mental models, perspectives – and a technical one – know-how skills".

Barney, Wright and Ketchen (2001) suggest that in the resource based view, a firms' competitive advantage derives from their preferential access to idiosyncratic resources such as tacit knowledge. Peteraf (1993) argues that innovating enterprises need to move beyond the basic tenets of threshold resources and explicit knowledge to gain differential advantage to rivals. Threshold resources consist of tangible and intangible capabilities "essential for the organisation to be able to compete in a given market" (Johnson, Scholes and Whittington, 2006, p.119). Knowledge can be considered both a tangible and intangible resource. Organisations have ample access to tangible or explicit knowledge as it is "pinned down verbally in writing or electronically, and can therefore be communicated and distributed" (Seufert, vonKrogh and Bach, 1999, p.183). The widespread availability and ease of access to explicit knowledge diminishes the innovative opportunities available to organisations. Therefore, Barney, Wright and Ketchen (2001) contend that organisations need to build upon their threshold capabilities to create unique resources that critically underpin competitive advantage and that others cannot imitate quickly or obtain.

The growth of a distinctive enterprise relies on its ability to produce high quality internal knowledge. Consequently, innovative organisations need to examine the "holistic view of knowledge, that is to say the integration of explicit and tacit knowledge" (Seufert, vonKrogh and Bach, 1999, p.183). Tacit knowledge is paramount to an organisation's distinctiveness as it possesses technical and cognitive dimensions (Seufert, vonKrogh and Bach, 1999). These dimensions are embedded in the workforce and are extremely difficult to replicate, thus, encapsulating the core principles of the resource based view of innovation.

Sustainable competitive advantage in the resource based view results form the inimitability, rarity and non-tradability of the intangible resources (Barney, Wright and Ketchen, 2001; Cho and Pucik, 2005). Thomas, Sussman and Henderson (2001) and Mesquita, Anand and Brush (2008) also advocate that holistic knowledge has the ability to create distinctive and inimitable competitive advantages for a single firm within the meso environment.

Nevertheless, Pyka (2002) argues that it would be extremely demanding, challenging and time consuming for a meso level enterprise to dedicate its entire workforce to the creation of complex tacit and explicit knowledge. The attainment of complex knowledge could result in a depletion of resources, expertise and creativity in organisational units and departments (Pyka, 2002). Furthermore, Nooteboom (2000, p.922) contends that it may be outside the capabilities and competences of an enterprise to create complex knowledge as “such knowledge is locked into the subconscious mind, skills, team and organisational cultures”. Roberts (2000) asserts that firms should intertwine their internal competitiveness with external collaborative strategies to build and enhance their knowledge repertoires.

The resource based view is very much evident throughout the literacy paradigm of science communication, where practitioners and policy makers create scientific knowledge within the boundaries of the macro and meso environments. The linear transfer of knowledge to the micro public closes the door to the co-production of complex knowledge between policy, practice and public levels. Policy makers and practitioners are co-aligned in their thinking to Pyka (2002) who suggests that the creation of complex knowledge with multiple levels in society is extremely challenging and time consuming. The exclusion of public knowledge in the resource based view of science communication created an expert-laity divide between the science community and the public (Dornan, 1990; Kurath and Gisler, 2009).

3.3.2.2 The Institutional View

Conroy (2007, p.32) argues against the over reliance on the resource based view stating that it is “highly unlikely that all companies will be able to have a conveyor belt of self-generated ideas to capitalise on”. Conroy (2007) also suggests that it is challenging for organisations to continually champion innovation in volatile markets and rapidly changing societies. Hughes, Duane-Ireland and Morgan (2007) mobilise a limitation to the resource based view stating that it can be hindered by an organisations lack of resources, knowledge and social capital. Alternatively, the institutional environment in which organisations operate has an important impact on the collaborative strategies they pursue (Barney, Wright and Ketchen, 2001). An institutional view expresses a normative rationality of partner selection, where alliances are formed for the conformity of social justification and social obligation (Lin, Yang and Arya, 2009). The institutional view conceptualises a dyadic exchange process where partnering firms engage in additive relationships, transferring and gaining something tangible or intangible, actual or symbolic (Houston and Gasseinheimer, 1987).

Partnering firms can sometimes be cautious of their initial dyadic relationships with external organisations, if the level in which they operate is motivated by competitive strategies (Roberts, 2000; Yang, Lin and Lin, 2010). The exchange of knowledge between organisations in the institutional view involves bidirectional exchanges which resemble Bagozzi’s (1975) neoclassical concept of quid pro quo transfer, as the partnering firms have no desire to form social exchange relationships with the external firm (Ivens and Blois, 2004). Yang, Lin and Lin (2010) propose that dyadic relationships embrace two distance concepts; technical distance and status distance. Technical distance refers to the degree of dissimilarity in the technology base between the two partnering firms. Lin, Yang and Arya (2009) contend that the main benefit to result from the restricted alliance is legitimacy. Legitimacy provides critical social resources that facilitate and complement financial and physical resources (Lin, Yang and Arya, 2009). Alternatively, bidirectional alliances can improve the status of the interacting firms. The perception of improved status can be beneficial to an organisation as it enhances reputation, as well as increasing the possibilities of creating subsequent links with other firms in the meso environmental level (Yang, Lin and Lin, 2010).

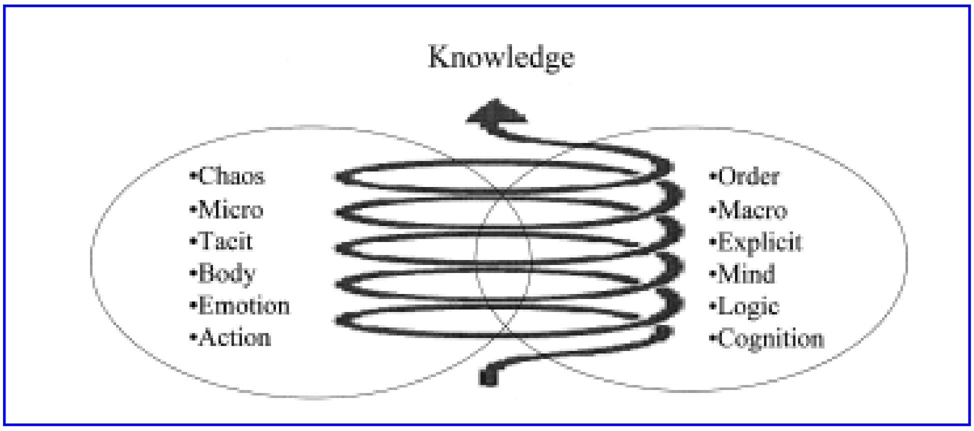
The institutional view underpins the thinking behind the public understanding of science paradigm as it endeavours to increase the status of the science community, as well as eliminating the technical distance between the policy and practice levels with the public (Stirling, 2006). The bidirectional communication in science offset the knowledge deficit but created public hostility and conflict, as the science community communicated what they perceived the public ought to know instead of identifying what the public want to know through meaningful dialogues (Borchelt, 2001). O'Shaughnessy (1996) recognises that the didactic approach to science communication must be reconfigured beyond dyadic forms of communication to relational exchanges between macro, meso and micro environmental levels.

3.3.2.3 The Relational View

The relational view asserts that competitiveness arises through interfirm collaborations (Mesquita, Anand and Brush 2008). The relational view emphasises the trend of multiple alliances with multiple partners, as firms become embedded in intricate webs of interfirm networks (Koka and Prescott, 2002). The bidirectional levels of communication in the institutional view are replaced by multi-directional and multi-dimensional communication processes and knowledge flows between the co-operating partners, giving rise to what Nill and Kemp (2009) denote as systems of interconnected institutions which create, store and transfer insights, knowledge and skills. Furthermore, the relational view co-produces complex knowledge through spirals (Nonaka, Toyama and Konno, 2000). Nonaka, Toyama and Konno (2000) suggest that spirals denote dialectical thinking to knowledge creation as illustrated in Figure 3.3.2.3.

Nonaka, Toyama and Konno (2000) suggest that the creation of spiral knowledge through action and interaction captures the dynamic process of knowledge creation as opposed to the static and passive information processing machines inherent in the resource and institutional based views.

Figure 3.3.2.3 Relational Knowledge created through a Spiral



Source: Nonaka, Toyama and Konno (2000, p.6)

Collaboration between meso level organisations creates more desirable platforms for inter-partner learning and allows one partner to appropriate and internalise resources that another partner contributed (Dussauge, Garrette and Mitchell, 2000). A relational view to innovation understands the micro-behaviour of the internal organisation, whilst also understanding the wider setting for knowledge creation, transfer and exchange (Lundvall, 2007). Relational views also emphasise the distribution of power and social learning through interacting social practices between macro, meso and micro environmental levels in innovation (Lundvall, 2007; Tuomi, 2012).

The science-and-society and science-in-society paradigms are entrenched within the relational view as policy makers, practitioners and the public embrace new forms of interaction and exchange. Macro and meso environmental levels move away from the linear creation of knowledge to spiral co-productions of knowledge which deemphasise power and control and reemphasise dialogue, learning and participation between policy makers, practitioners and the public (Nonaka, Toyama and Konno, 2000).

In summary, this section highlights the multiple levels of innovation and the evolutionary views of innovation which comprise of resources, institutions and relationships. Each of the views are present in the science communication paradigms where each view frames the issues differently, poses characteristic questions and offers prepared solutions to the acquisition and production of explicit or tacit knowledge and tangible or intangible resources (Bauer, Allum and Miller, 2007). The next section illustrates how closed and open network models of innovation provide a holistic understanding of participatory processes in science communication.

3.4 From Closed to Open Networks in Science Communication

As the previous sections outlined, innovation is moving towards the intersection of invention and insight at multiple levels, as organisations see the value of blurring the boundaries between macro, meso and micro level environments (Council on Competitiveness, 2005; Chesbrough, 2011). Dodgson and Hinze (2000) effectively capture the transition of the innovation process in five stages:

1. Push Strategy – Simple linear sequential process;
2. Pull Strategy – Simple linear sequential process;
3. Coupling Model – Sequential, but with feedback loops;
4. Integrated Model – Parallel development with integrated processes; and
5. Systems Integration and Networking Model (SIN) – fully integrated collaborative processes.

Closed models of innovation are evident in the push and pull strategies as communication and collaboration is confined within an organisation, often under a complete secret to the outside world (Lee, Olson and Trimi, 2012). As innovation moves from closed linear sequences to fully integrated processes, the process becomes more complex and iterative, as meso environmental organisations are more receptive to openness and interaction to access knowledge (Chesbrough and Appleyard, 2007). Open innovation refers to ways of sharing with others and invites participation from distributed inter-organisational networks, rather than from single firms (Perkmann and Walsh, 2007; Chesbrough 2011).

The theme of open innovation is extremely appropriate for science communication as Chesbrough and Appleyard (2007, p.60) define open innovation as “the pooling of knowledge for innovative purposes where the contributors have access to the inputs of others and cannot exert exclusive rights over the resultant innovation”. Open innovation gives an equal status to its participatory organisations and eliminates the hierarchical ownership of knowledge and learning, as openness is facilitated from the outside-in and the inside-out (Chesbrough, 2011). Tuomi (2012, p.738) also supports open and interactive communities of practice as the author suggests that new “functionalities and propensities are in effect thrown from the upstream to a downstream field of interacting social practices” where the macro, meso and micro environmental levels mutually construct the innovation process and social learning.

Rose et al. (2009) argue that innovation is not linear, it is in fact interactive and iterative possessing feedback loops for double-loop learning and triple-loop learning. Perkmann and Walsh (2007) also indicate that open innovation is interactive, iterative, non-linear and involves multi-agent relationships. The avocation of interactive relationships further reinforces the appropriateness of open innovation to science communication as the science community and the public establish mutually beneficial exchange relationships over the long term.

The sharing and transfer of complex knowledge, alongside the co-creation of value in open innovation are dependent on the formation of interactive relationships (Chesbrough, 2011). Innovation involves the process of interaction between firms and other organisations (Nooteboom, 2000). These interactions occur at multiple dimensions such as vertical, horizontal and social network structures. Borzel and Heard-Laureote (2009) ascertain that each dimension integrates with one other through non-hierarchical modes of coordination to compliment the innovation policy system. “Vertical coordination refers to managing relationships between various levels of government and proceeding from priority-setting to policy implementation. Horizontal coordination is the management of interdependent policies across the state administration” (Pelkonen, Teravainen and Waltari, 2008, p.242).

Gulati, Nohria and Zaheer (2000) also emphasise the integration of horizontal and vertical exchange relationships within open innovation networks. According to

Rothaermel and Hess (2007), all resource integrators work together to integrate, build and reconfigure internal and external competences to enhance the dynamic capabilities of each partnering firm. Kisby (2007) fortifies the need for partnering firms to establish a dialectical model of networks at the meso level of the environment, simultaneously interacting with both policy makers at the macro environmental level and the public at the micro environmental level. Nonaka (1994) considers open innovation to integrate top-down, middle-up-down and bottom-up knowledge creation processes which synergise money, knowledge and people. The middle-up-down model views all stakeholders as important contributors to the innovation process, working together horizontally and vertically (Nonaka, 1994). In contrary to this, Nonaka (1994) maintains that top-down models of innovation give hierarchical power to macro environmental levels and bottom-up processes integrate the viewpoints of the micro environment. Taken together, all three models emphasise a balanced coordination of power and knowledge production (Nonaka, 1994) for innovation.

Science communication processes could benefit from a dialectical model as it would help create and strengthen policy, practice and public participation alliances (Silverman and Baum, 2002). Nooteboom (2000) evaluates how cooperation between structures in organisations as well as the coordination of these relationships at macro, meso and micro levels, facilitates collaborative learning and innovation. This networking of networks approach moves away from a centralised top down model and pays much more attention to reciprocal dialogue and mutual learning processes (Inzelt, 2008). Science communication processes are currently in transit between closed and open models of innovation as policy, practice and public levels interact, exchange views, share knowledge and listen (Burgess and Clark, 2006).

The propensity for science communicators to engage in meaningful participatory processes depends on the characteristics of the science communication network as well as the formation of the network and the co-innovation process between the policy, practice and public levels, which in turn are discussed.

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3.4.1 Network Characteristics

There is no one pioneering definition in existence for networks. According to Borgatti and Foster (2003, p.992) "a network is a set of actors connected by a set of ties". Alternatively, Arya and Lin (2007, p.698) define a collaborative network as "a collection of loosely connected or closely knit organisations that share resources". In spite of the varying definitions, connectedness is a key term used in both. Connectedness influences network characteristics. Rowley (1997) and Palmatier (2008) express two dominant characteristics in networks which are network density and network attractiveness, centrality or diversity. Palmatier (2008) asserts that network density examines the level of interconnectedness among network members. Interconnectedness is correlated to the number of ties between network members. According to Palmatier (2008) the more ties a network member develops is said to have a profound impact on cooperation levels and knowledge transfer. Alternatively, Rowley (1997) suggests that sparsely connected networks concentrate on the relational ties between few stakeholders that form strong bonds over time and network membership is restricted to an elite few.

Gulati, Dialdin and Wang (2002, p.289) assert that "there are many ways to categorise inter-firm ties, such as strong versus weak ties, cohesive versus bridging ties, horizontal versus vertical ties, and institutional versus non-institutional ties". Uzzi and Lancaster (2003) also predicate the value of arm's length versus embedded ties. Arm's length ties involve impersonal, atomistic and opportunistic relationships where the actors are motivated by their own self-interests, whereas embedded ties shifts the logic of opportunism to the logic of trustworthiness and co-operative behaviour, creating a new basis for knowledge transfer and learning (Uzzi and Lancaster, 2003).

Network ties are central to the understanding of network density (Gulati, 1995; 1999; Gulati, Nohria and Zaheer, 2000; Inkpen and Tsang, 2005; Capaldo, 2007). According to Ingram and Roberts (2000), networks can be formed through friendship ties. Friendship ties occur horizontally in the meso environment where organisations collaborate to facilitate information exchange. The exchange of information through friendship ties moves firms beyond informal transfers to mutually beneficial exchanges. The process and outcomes of innovation are determined by the ties organisations are involved in. According to Gulati and Gargiulo (1999) ties satisfy resource needs and help firms to cope with exogenous constraints.

The second network characteristic liable to influence an organisations decision is network attractiveness, diversity or centrality (Rowley, 1997; Gulati, Dialdin and Wang, 2002; Palmatier, 2008). Seufert, VonKrogh and Bach (1999) in line with Chakravorti (2004) maintain that the attractiveness of a network hinges on the skills, competences, knowledge and positions of the network players involved. The appeal of a network also depends on the absorptive capacity of an organisation (Cohen and Levinthal, 1990; Powell, Koput and Smith-Doerr, 1996; Tsai, 2001; Zaheer and Bell, 2005). An organisation becomes less reliant on network collaborations if they have high levels of absorptive capacity as it means they can invest more in their own research and development, and subsequently produce more innovations (Tsai, 2001).

Absorptive capacity integrates and assimilates prior related knowledge with new knowledge and applies it to commercial ends. Cohen and Levinthal (1990) maintain that the ability of an organisation to recognise new information, assimilate it with prior related knowledge and apply it to an organisational end constitutes absorptive capacity. Tsai (2001, p.998) maintains that absorptive capacity can increase the attractiveness of a network structure as these organisations have the capacity to absorb knowledge which will ultimately “enhance its innovation and performance”.

Networks interconnect the policy, practice and public levels in science communication. Science communication embraces Arya and Lin’s (2007) concept of a collaborative network where the three levels share scientific resources, information and knowledge. Science communication enhances the absorptive capacity of the system of science, as collaboration within and across the policy, practice and public levels facilitates the co-production of new knowledge (Pallett, 2012).

3.4.2 Interorganisational Networks

Interorganisational networks have become a central area of discussion in the innovation literature. The process of networking has been pioneered by authors such as Achrol (1997); Gulati and Gargiulo (1999); Cowan, Jonard and Zimmermann (2007); Borzel and Heard-Laureote (2009) and Yang, Lin and Lin (2010).

Borzel and Heard-Laureote (2009) suggest that interorganisational networks have grown in prominence due to their ability to integrate the interactions and functions of many separate but interdependent organisations, by co-ordinating their actions through interdependencies of resources and interests. Interorganisational networks provide access points for macro, meso and micro level organisations to co-produce knowledge and gain access to external resources. Interorganisational networks embrace openness where industry boundaries are blurred and collaboration is encouraged through network ties between organisations. However, Achrol (1997, p.59) posits that "the mere presence of a network of ties is not a distinguishing feature of a network organisation". According to Achrol (1997) a set of ties does not constitute a network because it would lead one to believe that all enterprises collaborate and cooperate within one supra network structure. Achrol (1997, p.59) denotes quality as a defining term for networks as the author defines a network organisation as "distinguished from a simple network of exchange linkages by the density, multiplexity, and reciprocity of ties and a shared value system defining membership roles and responsibilities". Science communication embodies Achrol's (1997) interpretation of a network organisation as exchange processes are complex between the multiple coordinating levels of policy, practice and the public.

Klint and Sjoberg (2003) suggest that relational networks arise in two ways – organically and/or strategically. Organic networks are built through a natural progressive relationship between organisations who share mutual interests in similar marketplaces. Conversely, strategic networks are created deliberately between enterprises that have specific objectives or goals to obtain (Klint and Sjoberg, 2003). These two network development processes are directly comparable to Pyka's (2002) classification of networks as formal and informal. Klint and Sjoberg (2003) and Pyka (2002) also maintain that it is possible for formal and strategic networks to develop from progressive and organic relationships as opposed to the distinctive formation of one or the other.

Another method of network formation highlighted by authors is the generative emergence of explorative or exploitative relationships (Powell, Koput and Smith-Doerr, 1996; Capaldo, 2007). Exploration is similar to the organic development of network relationships in that it involves experimenting with new alternatives and exploring new opportunities and relationships (Powell, Koput and Smith-Doerr, 1996). Conversely, exploitation aligns with strategic configurations in that organisations exploit existing relationships to refine and extend existing knowledge bases. He and Wong (2004) contend that exploration implies firm behaviours are characterised by search, discovery, experimentation, risk taking and innovation, while exploitation implies firm behaviours are characterised by refinement, implementation, efficiency, production and selection. He and Wong (2004) posit that the basic problem confronting organisations is the devotion of proportionate amounts of time and energy to both exploitation, ensuring its current viability and exploration to ensure its future viability.

Science communication integrates both exploitative and explorative relationships; however, these relationships are formed between policy and practice levels. Science communication for effective participation extends the formation of exploitative and explorative relationships beyond policy and practice levels to the inclusion of the shared interests and knowledge of the micro public level (Stirling, 2008; Pallett, 2012).

Maak (2007) denotes the weaving of the public level in network formation as complex as it engages multi-level stakeholders in a participatory process that creates resonance, trust and ultimately stakeholder social capital. “Social capital refers to networks, norms, trust and mutual understanding that bind together the members of human networks and communities, and enable participants to act together more effectively to pursue shared objectives” (Widen-Wulff and Ginman, 2004, p.449). Social capital revolves around the maintenance and progression of relationships in networks. According to Mu, Peng and Love (2008, p.88), the purpose of social capital is to facilitate the flow of knowledge between network partners as “social capital supports the collective generation of new ideas through exploiting, mobilising, acquiring and transferring knowledge”. Bonding social capital (Smith, 2006) promotes continuous coordination and cooperation for mutual learning in networks. As network players acquire new knowledge, their connections ripen into embedded relationships (Borgatti and Foster, 2003). Each partner in an embedded relationship contributes to the exchange process. The exchanged information can generate into new knowledge and innovations for organisations.

In summary, the cultivation of interorganisational networks in science communication can strengthen the linkages and ties between policy makers, practitioners and the public. Interorganisational networks also empower the exchange of insights, ideas and inputs from multiple stakeholders, co-creating value for innovation. In the innovation literature, co-creation and innovation have been combined as co-innovation (Lee, Olson and Trimi, 2012) which is discussed in the next section.

3.4.3 Co-Innovation

Lee, Olson and Trimi (2012, p.819) label co-innovation as a "platform where internal, external, collaborative, co-creative ideas can be converged to create organisational and shared value". Co-innovation is a particularly effective concept for science communication as the key element of co-innovation is the convergence, collaboration and co-creation of shared ideas, values and experiences. Science communication, through the integration of the policy, practice and public levels emphasises co-innovation as the exchange, interaction and communication processes create new value and experiences for all stakeholders (Lee, Olson and Trimi, 2012). Co-innovation relies on the convergence, collaboration and co-creation between structures in science communication as well as the coordination of these exchange relationships at the various environmental levels (Lee, Olson and Trimi, 2012). Co-innovation emphasises relationships at "the micro level of the research organisation, the sector or meso level of the idea innovation network and the macro level of government policy" (Hage, Jordan and Mote, 2007, p.731). Each level in co-innovation inter-relates and exchanges knowledge to ensure mutual learning experiences (Lee, Olson and Trimi, 2012). Co-innovation in science communication resembles a networking of networks structure. Provan, Fish and Sydow (2007) equate this networking of networks to a whole network approach where the focus is not on the meso environment of science communication, but on the properties and characteristics of the network as a whole.

The crux of co-innovation according to Lee, Olson and Trimi (2012) surrounds the network effects of engagement, experience and co-creation for value that is difficult to imitate. Co-innovation also focuses on the holistic concept of ‘we’ in science communication as opposed to ‘they’ versus ‘we’ (Trench, 2008; Lee, Olson and Trimi, 2012). Trench (2008) delineates the macro environmental levels orientation to the public as ‘they are hostile, they are ignorant and they can be persuaded’ in the science literacy paradigm. Throughout the public understanding of science paradigm, the orientation shifted towards ‘we find out their views; they talk back’ (Trench, 2008). In the science-and-society paradigm, the macro environmental level reflected on ‘they and we shape the agenda; they and we negotiate meanings’ (Trench, 2008). In co-innovation and the science-in-society paradigm, participatory processes do not segregate the environmental levels of innovation; rather the processes perpetuate a holistic ‘we’ approach to relational exchanges, interaction and communication (Lee, Olson and Trimi, 2012).

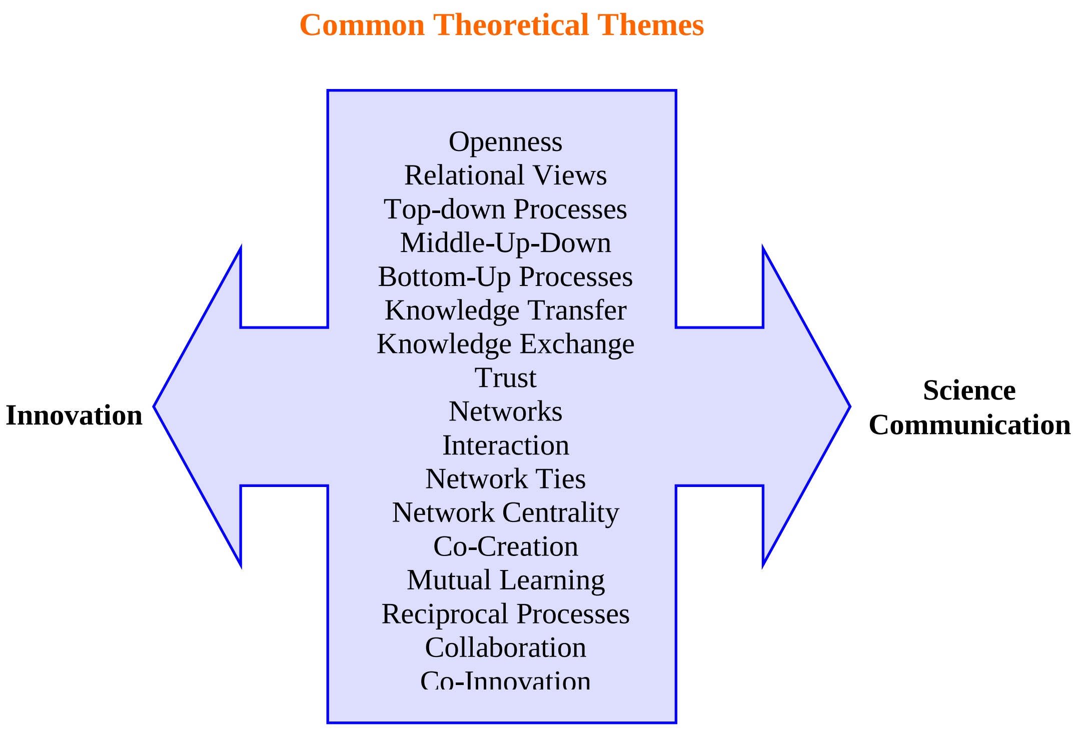
A co-innovative approach is extremely prevalent for participatory processes in science communication. As Lee, Olson and Trimi (2012, p.829) suggest, “what used to be closed systems have given way to open systems emphasising co-innovation focused on creating shared value”. The simple linear model of explaining science to the public has been replaced by a multi-directional and multi-level concept of co-innovation. Co-innovation is more interactive in the way of a citizen push approach promoting innovative experiences and value with and for everyone. The term ecology of innovation was coined for such an approach by Bora (2005). An ecological system of co-innovation looks beyond competition and cooperation, emphasising a co-created network approach, capturing the appropriateness of innovation to science communication.

3.4.4 A Summary of Innovation and Science Communication

Innovation complements participatory processes in science communication as innovation is an interactive process at the intersection of insight and invention.

Innovation through a multi-dimensional view reflects on how resources, institutions and relational views evolved in tandem with the science communication paradigms, creating economic as well as social value. The movement from closed to open and collaborative models of innovation (Lee, Olson and Trimi, 2012) further reflects the applicability of innovation theory to science communication as the innovation themes, as illustrated in Figure 3.4.4 provides an analytic understanding of participatory processes in science communication.

Figure 3.4.4 Common Theoretical Themes between Innovation and Science Communication



Innovation theory enhances the processes of exchange, interaction and communication between top-down, middle-top-down and bottom up levels (Nonaka, 1994) of science communication. Co-innovation for science communication provides compelling experiences with network effects for value creation (Lee, Olson and Trimi, 2012). Co-innovation is the convergence, collaboration and co-creation of shared ideas, values and experiences between the open levels of science communication, which illustrates the appropriateness of innovation theory in developing a better understanding of participatory processes in science communication.

The integration of science communication with social marketing and innovation theory, thus far, developed a better understanding of participatory processes in science communication. The integration of the three literature areas also facilitates the development of process indicators for science communication and its measurement which is analysed in the next section.

3.5 Developing Process Indicators for Science Communication

Chapter two identified a fourth generation of indicators for science communication; namely process indicators as illustrated in Table 3.5. Process indicators include knowledge, intangibles, networks, demand, clusters, management techniques, risk/return and system dynamics (Milbergs and Vonortas, 2004; Stone et al., 2008; Rose et al., 2009). The movement towards enhanced process indicators for science communication recognises the societal impact of change as well the economic value of input-output indicators.

Powell and Colin (2008, p.128) delineate processes as "interactive and iterative methods of deliberation among citizens and between citizens and government official with the purpose of contributing meaningfully to specific public policy decisions in a transparent and accountable way". Powell and Colin (2008) define processes at a micro level but fail to capture the interplay of macro, meso and micro level dynamics from an integrative perspective.

Processes are interactive and iterative methods of deliberation across and between policy, practice and public levels of science communication, shifting the analysis from input-output structures to the alignment of interconnected processes linked together in a web of relationships – wherever and however those relations are connected (Powell and Colin, 2008; Roberts, 2011).

The importance and also the limited applicability of the fourth generation process indicators to science communication, social marketing and innovation are illustrated in Table 3.5. More specifically, Table 3.5 illustrates the four key process indicators prevalent among all three streams of literature which are knowledge, intangibles, networks and system dynamics.

Table 3.5 Relevance of Process Indicators to Literary Fields

Literary Fields / ***Process Indicators***	Social Marketing	Science Communication	Innovation Theory
Knowledge			
Intangibles			
Networks			
Demand		***	
Clusters			
Management Techniques			
Risk/Return			
System Dynamics			

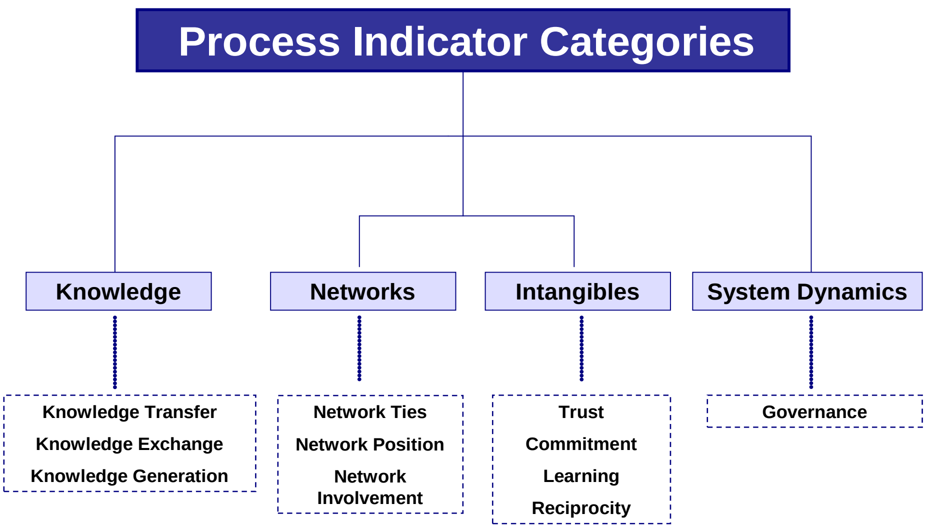
*** Demand in Science Communication Literature versus Demand in Science Policy

The four indicators of knowledge, intangibles, networks and system dynamics are evident in the literatures of science communication, social marketing and innovation theory. Appendix One illustrates in greater detail how these four process indicators were extrapolated. When the eight process indicators were compared across the literature, demand, clusters, management techniques and risk/return were not examined in the same way or context in science communication, social marketing and innovation theory.

The analysis of demand in science communication is important to policy makers, yet theorists and researchers are less preoccupied by its validity in the science communication literature. Policy makers are consumed by the need to measure demand for science in terms of computing the relevant human capital metrics. However, demand for science as an indicator has received far less attention in the science communication literature as theorists are more concerned with the science literacy, public understanding of science, science-and-society and science-in-society paradigms in addition to the respective deficit models. The disconnect between policy makers and science communicators illustrates how science and policy do not evolve in congruence with one another (Jones, 2010). Instead, policies relating to science react to scientific change as opposed to transitioning in tandem with science (Jones, 2010).

The interconnections between the process indicators of knowledge, networks, intangibles and system dynamics are illustrated in the conceptual framework of process indicators in Figure 3.5. The first layer of the process indicator model highlights the four indicators chosen from the fourth generation process indicators framework (Milbergs and Vonortas, 2004; Stone et al., 2008; Rose et al., 2009). Bellavista and Sanz (2009) assert that knowledge reflects the skills, experience and abilities of people. Networks represent an "organisation's relations with its external stakeholders and the perceptions that they hold about the organisation" (Kong, 2010, p.163). Intangibles such as trust, commitment, learning and reciprocity are viewed as antecedents to, and outcomes of relationships (Hunt and Morgan, 1994). The last indicator of governance in system dynamics relates to the structural alignment of the interconnected parts, which are linked together through webs of relationships (Roberts, 2011).

Figure 3.5 Process Indicators



The four process indicator categories are deconstructed into eleven process indicators. The eleven indicators comprise of knowledge transfer, knowledge exchange, knowledge generation, network involvement, network ties, network position, trust, commitment, learning, reciprocity and governance. Each indicator was prevalent among the literature of science communication, social marketing and innovation, as comprehensively illustrated in Appendix One. There is little controversy relating to the contextual importance of these indicators in the literature, as conveyed in this chapter and the preceding chapter on science communication and its measurement. The aim of the remainder of this chapter is to compare and contrast the eleven process indicators from each of the fields and to illustrate and validate their inclusion in a measurement framework.

3.5.1 Knowledge

Knowledge indicators comprise of knowledge transfer, knowledge exchange and knowledge generation. Each of the knowledge process indicators are compared and contrasted across the three streams of literature in the section below. The chosen definitions for each of the knowledge indicators in this study are given in Table 3.5.1.

Table 3.5.1 Knowledge Process Indicators

Indicators	**Construct Definitions**
Knowledge Transfer	Knowledge transfer is a unidirectional and logical flow of information from knowledge producers to knowledge users (Jacobson, 2007, p.117).
Knowledge Exchange	Knowledge exchange means interactivity, engagement and a propensity to act on both sides. Knowledge exchange is more than listening, it implies shared learning and communication between equal problem solvers (Prahalad and Ramaswamy, 2004, p.6)
Knowledge Generation	Knowledge generation is a continuous process whereby individuals and groups within a firm and between firms share tacit and explicit knowledge (Choi and Lee, 2002, p.176)

3.5.1.1 Knowledge Transfer

Knowledge transfer is an important concept across science communication, social marketing and innovation. However science communication and innovation differ in their understanding of knowledge transfer compared to social marketing. In science communication, the focus is on the one-way flow of information (Miller, 2001; Burns, O'Connor and Stocklmayer, 2003). Alternatively, Kramer and Wells (2005) as well as Jacobson (2007) substitute one-way flows for unidirectional flows. In spite of the semantic terminology, authors are in agreement that information moves from experts in the science community down to the public level of the laity (Dornan, 1990; Miller, 2001).

Innovation, like science communication asserts that transmission and receipt are two necessary components to knowledge transfer (Grant, 1996). Nooteboom (2000) operationalises knowledge transfer as an iterative process involving experience and learning. Likewise, Inkpen and Tsang (2005) denote the process element to knowledge transfer.

Alternatively social marketing perceives knowledge transfer and knowledge exchange as interrelated terms (Bond, Houston and Tang, 2008). The one-way or unidirectional flow of knowledge from knowledge transmitters to knowledge receivers embraces a hierarchical authoritative strategy, where few stakeholders are involved and the transmission episode is quicker and less contentious than a cooperative strategy (Roberts, 2000).

The operational definition which is being used for this study defines knowledge transfer "as a unidirectional and logical flow of information from knowledge producers to knowledge users" (Jacobson, 2007, p.117), as it highlights a fluid and sequential flow of information from the producer to the consumer, clearly demarcating the boundaries between levels.

3.5.1.2 Knowledge Exchange

Knowledge exchange is an indicator which the three streams of literature emphasise. Knowledge exchange is a cornerstone concept in social marketing. Ballantyne and Varey (2006) emphasise three approaches to knowledge exchange: hierarchical, inter-functional and network exchange. Alternatively, Bagozzi (1975); Juttner and Wehrli (1994) and Glenane-Antoniadis et al. (2003) disaggregate exchange into three facets namely restricted, generalised or complex exchange. Heide and John (1992, p.35) neatly define knowledge exchange as "a bilateral expectation that parties will proactively provide information to the partner".

Science communication theorists in a similar way to social marketing, view knowledge exchange as a two-way flow of communication (Burns, O'Connor and Stocklmayer (2003). Gregory, Miller and Palen (1999) extend the communication orientation by denoting the process as a negotiation rather than a one way street which establishes trust, acknowledges the social in science and facilitates public participation. Shared attributes become central to knowledge exchange (Jackson, Barbagallo and Haste, 2005) in science communication as Logan (2001) argues the system becomes multi-directional when transmission works from the top-down and the bottom-up, to incorporate the integration of knowledge, ideas, attitudes and beliefs (Jackson, Barbagallo and Haste, 2005).

Among the innovation studies, Uzzi (1997) and Kale and Singh (2007) assess knowledge exchange by its classification as codified or explicit knowledge and tacit, uncodified or implicit knowledge (Bellavista and Sanz, 2009). Innovation academics in classifying knowledge are more concerned with how it is disseminated from one social actor to another. Kale and Singh (2007) argue that exchange involves disseminating individual and organisational held alliance management knowledge while Dyer and Hatch (2006) see knowledge exchange as an interfirm knowledge sharing routine.

In spite of the varying concepts and terms used across the three literature fields, "knowledge exchange means interactivity, engagement and a propensity to act on both sides. Knowledge exchange is more than listening; it implies shared learning and communication between equal problem solvers" (Prahalad and Venkat, 2004, p.6). This chosen definition incorporates several dimensions of exchange. Firstly, there are at least two parties (Bagozzi, 1975). Secondly, it goes beyond listening to the bilateral exchange of ideas, knowledge and values and lastly, each party learns from the process. Knowledge exchange also represents an open system where societies of networks are open to outside connections (Roberts, 2011).

3.5.1.3 Knowledge Generation

Knowledge generation is conceptually centred on the creation of new knowledge (Bodas-Freitas, 2007). All three literature areas acknowledge that the generation of knowledge can occur within an organisation or it can be strategically generated through external linkages (Choi and Lee, 2002; Bodas-Freitas, 2007).

In innovation theory, Choi and Lee (2002) alongside Hardy, Philips and Lawrence (2003) recognise that knowledge can be created organically within the boundaries of a firm, or strategically through dyadic relations with external partners in networks. In science communication, Braun (2008) predicates that knowledge generation can be both utilitarian and non-utilitarian, when the author maintains that non-utilitarian knowledge generation is inspired by curiosity and the search for truth. The utilitarian motive leads to a quest for chances to apply fundamental knowledge (Braun, 2008). In social marketing, Deshpande, Rothschild and Brooks (2004) associate knowledge generation to revolve around ideas.

Choi and Lee (2002, p.176) represent the chosen definition for the study as the authors predicate that knowledge generation is a "continuous process, whereby individuals and groups within a firm and between firms share tacit or explicit knowledge". Choi and Lee (2002) fruitfully reference the ability of firms to create knowledge through intra-firm and inter-firm relations or linkages (Roberts, 2011). Knowledge generation is a collective activity and does not reside to any one individual. Although ideas generate within the minds of individuals, it is the collective brainstorming (Deshpande, Rothschild and Brooks 2004) which converts ideas into transformative knowledge value for organisations.

3.5.2 Networks

Network indicators comprise of network involvement, network ties and network position. Each of the network process indicators are compared and contrasted across the three streams of literature in the section below. The chosen definitions for each of the network indicators in this study are given in Table 3.5.2.

Table 3.5.2 Network Process Indicators

Indicators	Construct Definitions
Network Involvement	Network involvement investigates the composition of the network – the identities, status, resources, access and other characteristics of the focal industry's alters and other nodes (Gulati, Nohria and Zaheer, 2000, p.205)
Network Ties	Network ties are connections between people which can be relatively tenuous (weak) or intensive (strong) depending on the frequency, intensity, intimacy and reciprocity of the interaction and connection (Kramer and Wells, 2005, p.430)
Network Position	A firm's position is measured through its centrality – the degree to which it is directly and indirectly connected to other organisations and the degree to which other organisations are connected through it (Hardy, Philips and Lawrence, 2003; Tsai, 2001)

3.5.2.1 Network Involvement

Network involvement is a critical construct in the development and formation of networks across all three streams of literature. In science communication, Thune (2007) and Inzelt (2008) argue that network involvement corresponds to the linkages and dialogue processes between actors in a network. Inzelt (2008) further compounds network involvement to be related to decentralisation as Inzelt (2008) advocates for the disaggregation of a centralised top-down model. In social marketing, Lefebvre (2009) contends that network involvement employs state of the art strategies to support change at all levels in society.

In innovation, authors agree on the collectivity component to network involvement (Dussauge, Garrette and Mitchell, 2000; Katsamakas, 2007). However, the work of Hamel, Doz and Prahalad (1989) and Walker, Kogut and Shan (1997) differs from traditional network involvement constructs in that these authors argue that involvement embodies a competitive or exploitative element to network formation. Parung and Bititci (2006) contest the exploitative nature to network involvement, defining it as a means of working together for mutual benefits, while Katsamakas (2007) is the only author to depict network involvement duration as being built on short term exchange episodes.

The definition chosen for this study extends Thune's (2007) linkages component where "network involvement investigates the composition of the network – the identities, status, resources, access and other characteristics of the focal industry's alters and other nodes" (Gulati, Nohria and Zaheer, 2000, p.205). This definition is comprehensive in nature and portrays the strategic element to network involvement, where actors and organisations external to the focal organisation are analysed, prior to the exchange of resources, skills, beliefs, values and information.

3.5.2.2 Network Ties

There is a complete consensus surrounding network ties and their respective facets in science communication, social marketing and innovation. Firstly, there is a consensus that network ties refer to connections, relationships and social relations between actors (Inkpen and Tsang, 2005; Kramer and Wells, 2005; Thune, 2007). The second facet to network ties denotes their quality, which is often examined in terms of the strength and weaknesses (Smith, 2006; Capaldo, 2007; Thune, 2007).

Kramer and Wells (2005, p.430) intertwine both facets as they define network ties "as connections between people which can be relatively tenuous (weak) or intensive (strong) depending on the frequency, intensity, intimacy and reciprocity of the interaction and connection". Kramer and Well's (2005) definition is the guiding definition for the measurement of network ties in this study as it acknowledges both strong and weak links between partnering organisations.

3.5.2.3 Network Position

Innovation studies use network position and network centrality interchangeably. It is argued that power determines an organisation's position in the network (Rowley, 1997; Dhanaraj and Parkhe, 2006). Alternatively, access to resources and knowledge outside the confinements of an organisation is another determinant of network position (Tsai, 2001; Zaheer and Bell, 2005). Alternatively, Cowan, Jonard and Zimmerman (2007) suggest that network positions can be used as a competitive tool and something that can be manipulated to increase performance, profits or control. Tsai (2001) and Hardy, Philips and Lawrence (2003) comprehensively define that a firm's position is measured through its centrality – the degree to which it is directly or indirectly connected to other organisations and the degree to which other organisations are connected through it. This comprehension of a network position has been selected as the chosen definition for this study as it denotes a systems approach to networking where complex exchanges take place. Complex exchanges according to Bagozzi (1975) enlarge the systems perspective. The integration of direct and indirect sequences of exchange generates an open or closed system of interdependent partners (Juttner and Wehrli, 1994; Glenane-Antoniadis et al., 2003), reflecting the direct and indirect connection proposed by Hardy, Philips and Lawrence (2003).

3.5.3 Intangibles

Intangible indicators comprise of trust, commitment, learning and reciprocity. Each of the intangible process indicators are compared and contrasted across the three streams of literature in the section below. The chosen definitions for each of the intangible indicators in this study are given in Table 3.5.3.

Table 3.5.3 Intangible Process Indicators

Indicators	Construct Definitions
Trust	Trust is when both partners share similar values, when communication in their relationship is healthy and when their relationship history is not characterised by one partner maliciously taking advantage of the other (Hunt and Morgan, 1994, p.24)
Commitment	Commitment creates strong links through direct connections and ongoing relationships which are built through repeated, sequential forms of interaction and obeying the rules of reciprocity, which evolve into a common understanding of mutual commitments and trust in the goodwill of others (Kramer and Wells, 2005, p.430)
Learning	Learning is a complex, multi-dimensional construct occurring at different cognitive levels … and encompassing multiple sub-processes such as information acquisition, information dissemination and shared interpretation (Hult and Ferrell, 1997, p.98)
Reciprocity	Reciprocity occurs when a firm shows the partner its willingness both to share the benefits of good economic opportunities in the uncertain future and to bear the possible risks and costs involved in collaboration. This willingness becomes a fundamental basis of trust and thus, a long term relationship between partners (Chung, Singh and Lee, 2000, p.6)

3.5.3.1 Trust

There is a consensus among authors in each of the literature fields that trust is an important indicator of relationship quality and it is also denoted as an antecedent to relational processes (Hunt and Morgan, 1994). In the science communication field, there is general agreement towards a lack of trust among social actors or a crisis of trust between science and society (Bauer, Allum and Miller, 2007). As such, there is a preoccupation among analysts in this field to contain authority, power and control. Fernandez-Carro (2007, p.321) supports the notion that trust is about "limiting powers and about mutually reliable evaluation of results". Delgado (2010, p.564) argues that "trust is a matter of identity" which is intrinsic to an individual but externally, it is known to potential partners in the form of reputation, status and position.

Social marketing analysts reinforce the power aspect to trust. According to several authors, trust is about firms co-operating in a manner which is not malicious, spiteful, opportunistic, or indeed that will not impact negatively on the relationship between partners in a network (Hunt and Morgan, 1994; Achrol, 1997; Batt and Purchase, 2004). Hunt and Morgan (1994, p.24) assert that trust is “when both partners share similar values, when communication in their relationship is healthy, and when their relationship history is not characterised by one partner maliciously taking advantage of the other”.

In innovation, trust is commonly defined as an expectation (Gulati, 1995; Nooteboom, Berger and Noorderhaven, 1997; Nooteboom, 2000; Gulati and Sytch, 2008) that partners will perform according to the intentions and expectations of the relationship.

Hunt and Morgan’s (1994) comprehensive definition will guide the measurement of trust in this study as it denotes the equal and bilateral nature to trust, as well as minimising the risks associated with malicious and opportunistic behaviour among partners in the exchange relationship.

3.5.3.2 Commitment

Commitment is a construct which is prevalent to all three literature fields and it is believed to be another antecedent to the formation of relationships (Hunt and Morgan, 1994). Commitment is an elusive term which denotes the dedication and goodwill of partners to continually contribute to the stability of ongoing relationships (Gulati, 1995). Achrol (1997) argues that commitment is an attitudinal construct relating to the attachment, identification and affiliation of a relationship. Shah and Swaminathan (2008) explore commitment as involving pledges of continuity between alliance members and exchange partners. Kramer and Wells (2005, p.430) ineptly conceptualise commitment as “creating strong links through direct connections and ongoing relationships which are built through repeated, sequential forms of interaction and obeying the rule of reciprocity, which evolve into a common understanding of mutual commitments and trust in the goodwill of others”.

Kramer and Wells' (2005) represent the chosen definition for this study as it embroils the repetitive nature to ongoing partnerships, whilst also incorporating other intangible indicators such as trust, reciprocity and learning.

3.5.3.3 Learning

There is a consensus among authors in each of the literature fields that learning is an invaluable outcome to relational processes (Hunt and Morgan, 1994). Learning is a complex and multi-dimensional construct (Hult and Ferrell, 1997). Learning occurs through a process of knowledge acquisition, assimilation, integration and finally knowledge exploration (Yli-Renko, Autio and Sapienza, 2001). There are several dimensions to learning including individual learning (Davies et al., 2009); collective learning (Cotic-Svetina, Jaklic and Prodan, 2008); mutual learning (Hastings and Domegan, in press); organisational learning (Katsamakas, 2007) and interactive learning (Mu, Peng and Love, 2008).

Wolcott and Sengupta (2010, p.18) depict three tiers of learning in science communication: single loop, double loop and triple loop learning. "Single loop learning is what most organisations with a time bound, action oriented focus get stuck in … double loop learning organisations begin to question underlying assumptions and cultures, identify root causes of problems and are more open to rethinking strategies of functioning … triple loop learning is the highest form of organisational self-examination and reflexivity, in which people within organisations will examine the raison d'être - the organisations reason for existence".

In spite of the varying definitions and attributes to learning, the chosen definition for this research is that of Hult and Ferrell (1997, p.98) where they define learning as "a complex, multi-dimensional construct occurring at different cognitive levels … and encompassing multiple sub-processes such as information acquisition, information dissemination and shared interpretation". This definition acknowledges the process of learning as being multi-dimensional, occurring at multiple levels between exchange partners. It also outlines the gradual and incremental stages necessary for learning to occur, as social actors need to firstly, come into contact with knowledge external to their organisation through intra-firm relations, to then interpret and integrate the new knowledge into their current working environments where it can then be disseminated to other network members through inter-firm linkages.

3.5.3.4 Reciprocity

Reciprocation is a construct where authors from science communication, social marketing and innovation agree on the basic premise of the concept, although they use contrasting language. Palmer (1994) believes reciprocity in its truest form is the mutual disclosure of information. Tabanico and Schultz (2007, p.43) extend the mutuality component by stating that “reciprocating reduces the uncomfortable feeling of indebtedness”. Muthusamy and White (2005) argue that reciprocity is a form of moral obligation to the exchange process.

In essence, the defining examination of reciprocity for this study is from Chung, Singh and Lee (2000, p.6) where the authors articulate that “reciprocity occurs when a firm shows the partner its willingness both to share the benefits of good economic opportunities in the uncertain future and to bear the possible risks and costs involved in collaboration. This willingness becomes a fundamental basis of trust and thus, a long term relationship between partners”. This definition illustrates the quid pro quo nature to exchange as advocated by Bagozzi (1975).

3.5.4 System Dynamics

The system dynamic indicator comprises of governance. The system dynamic indicator is compared and contrasted across the three streams of literature in the section below. The chosen definition for the system dynamic indicator of governance in this study is given in Table 3.5.4.

Table 3.5.4 System Dynamic Process Indicator

Indicator	Construct Definition
Governance	Governance relates to how authority is exercised and how actor relationships are organised to overcome the resistance of actors to participate in coordination. There are various governance modes that are at the disposition of political actors, i.e. hierarchy, delegation, bargaining, or moral obligation (Braun, 2008, p.292)

3.5.4.1 Governance

Governance is a controversial construct in the literature areas as it relates to authority and management of organisations, networks and systems. Governance can be linked to openness and transparency or central authority (Braun and Schultz, 2010). Lundvall (2007) associates a balance to network governance where modes of centralisation and decentralisation are mixed. The imminent definition of governance for this study will be Braun's (2008, p.292) conceptualisation of how governance "relates to how authority is exercised and how actor relationships are organised to overcome the resistance of actors to participate in coordination". There are various governance models that are at the disposition of political actors such as a hierarchy, delegation, bargaining or moral obligation. Knight and Barnett (2010) allude that the effectiveness of governance will increase the propensity for governance trust, where people unite in a collective voice and are trusting of their systems of governance so much so, that they take an active role in political activities.

3.5.5 Summary of Process Indicators

In summary, there is a great deal of theoretical and empirical research on each of the eleven process indicators in the areas of science communication, social marketing and innovation. These eleven indicators provide an understanding of the participatory processes between science communicators and their conceptual development guides their measurement in data collection.

3.6 Chapter Summary

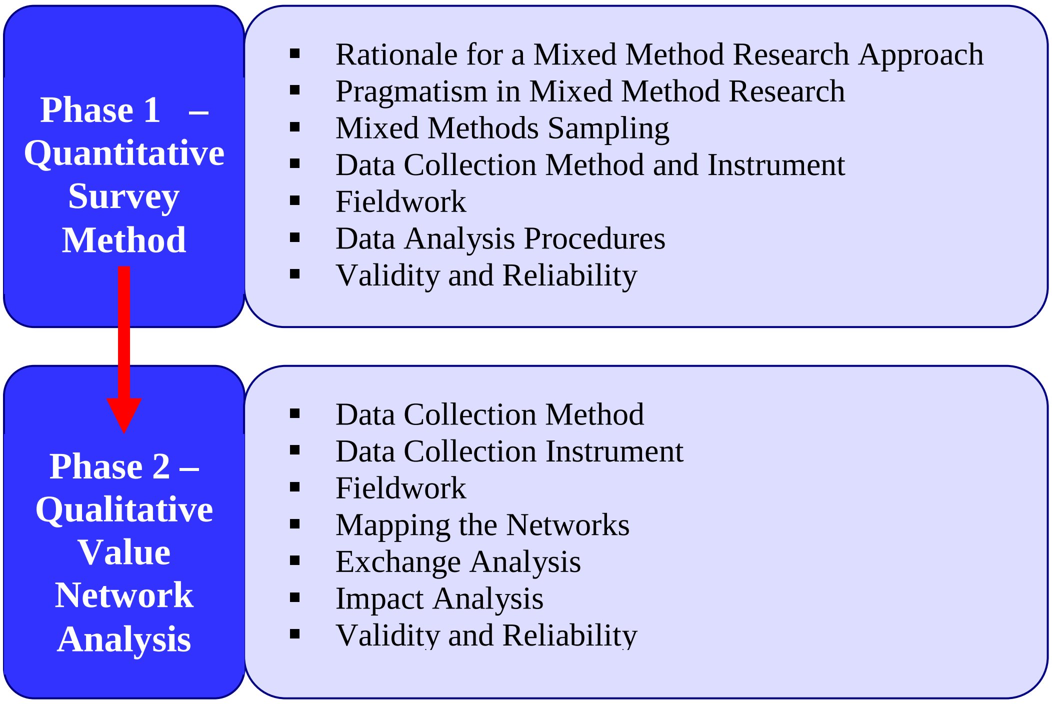
Science communication has come of age (Delgado, Kjolberg and Wickson, 2011) and is moving upstream towards holistic participation without a paddle (Stilgoe and Wilsdon (2009). Social marketing, through a total market approach and open innovation, through a multi-dimensional view co-innovate shared values, experiences and processes between policy, practice and public levels in science communication. The integration of science communication with social marketing and innovation theory has led to the conceptualisation of a new generation of eleven process indicators for science communication. The next chapter will outline the sequential mixed method approach chosen to empirically test these process indicators for science communication.

Chapter Four: Research Methodology

4.0 Introduction

The two phases of this research methodology are re-illustrated in Figure 4.0. The objective of this chapter is to discuss the sequential explanatory design of this study which includes phase one; the quantitative survey method and phase two; qualitative value network analysis. The purpose of conducting both quantitative and qualitative research in this study, is to examine '*how process indicators contribute to the understanding of activities between science communicators in Ireland*', as well as examining the secondary research objectives of this study (as revisited in section 4.1 below) and closing the research gaps on participation within the science communication literature. This chapter begins with a justification for mixed method research and a discussion relating to pragmatism as the philosophical partner for mixed method research (Johnson and Onwuegbuzie, 2004).

Figure 4.0 Overview of Sequential Explanatory Design



The remainder of the chapter examines the quantitative and qualitative data collection methods, instruments and analyses procedures employed in the mixed method design. First, the foundational primary research question and objectives from Section 1.5 in Chapter One are revisited in order to understand the methodological axioms guiding this research.

4.1 Research Question and Objectives

4.1.1 Primary Research Question

The primary research question of this study is how do process indicators contribute to the understanding of activities between science communicators in Ireland?

4.1.2 Secondary Research Objectives

The primary research question is supported by the following five secondary objectives:

Secondary Objective 1 specifically relates to the paradigms in science communication. Therefore, two parts to this objective have been devised; one theoretical and one empirical, as respectively outlined below:

(iii) To delineate the different science communication paradigms.

(iv) To understand the roles of science communicators in the process of science communication.

Secondary Objective 2: To establish the key science-policy interfaces in science communication.

Secondary Objective 3: To determine how process activities differ, if at all, between science communicators with policy, practice and public orientations.

Secondary Objective 4: To analyse how value is created between science communicators.

The primary research question and objectives underpinning this study influence the mixed method design chosen for this study. The rationale for a mixed methods research approach and a sequential explanatory design are discussed in the following section.

4.2 Rationale for a Mixed Method Approach

Mixed methods research approaches are emerging as the third methodological movement as they are perceived as a separate methodological orientation with their own worldview, vocabulary and techniques (Denscombe, 2008; Wheeldon, 2010). Sandelowski (2000) advocates for more mixed method research as the complexity of human behaviour mandates more complex research designs to capture them. Consequently, a mixed method approach is appropriate for this study as the behaviour of science communicators has become increasingly complex given the multifaceted nature to participation and the systems of exchange and interaction within science communication.

A key feature of mixed method research which is particularly salient to science communication is its methodological pluralism (Molina-Azor, 2011). Mixed method research captures the bigger picture by combining information from complementary quantitative and qualitative methods, allowing a more robust analysis of process activities (Ivankova, Creswell and Stick, 2006). In mixed methods research:-

> *"The overall purpose and central premise of mixed method studies is that the use of quantitative and qualitative approaches in combination may provide a better understanding of research problems and complex phenomena than either approach alone, incorporating the strengths of both methodologies and reducing some of the problems associated with singular methods" (Molina-Azor, 2011, p.8)*

Denscombe (2008) maintains that a mixed method approach improves the accuracy of data and avoids biases intrinsic to single-method approaches. The purposes of mixed methods research are numerous. Greene, Caracelli and Graham (1989) alongside Johnson and Onwuegbuzie (2004) and Teddlie and Tashakkori (2006) divide the functions and purposes of mixed method research into five categorisations; triangulation, complementarity, development, initiation and expansion, as illustrated in Table 4.2.

In complementarity, quantitative and qualitative methods are used to measure overlapping and different facets of a research question, producing an enhanced understanding of that research area (Greene, Caracelli and Graham, 1989). Complementarity differs from triangulation in that “the logic of convergence requires that different methods assess the same conceptual phenomenon” (Greene, Caracelli and Graham, 1989, p.259). Complementarity is appropriate to this study as the quantitative method examines the process indicators and the qualitative method assesses how process indicators create value through networks.

Development and expansion are also highlighted as important functions to this study as Greene, Caracelli and Graham (1989) argue that studies with a discernible rationale for a mixed method design match one or more of the five purposes. Development is particularly relevant to this study as a sequential mixed method design is employed. The qualitative component refines and explains the statistical results from the quantitative component by exploring participants’ views in more depth through semi-structured interviews (Ivankova, Creswell and Stick, 2006).

Greene, Caracelli and Graham, (1989) suggest that expansion aims for scope and breadth in a study. The quantitative element of this study focuses on the primary research question on how indicators contribute to the understanding of process activities between science communicators. The qualitative component assesses the process indicators in greater detail to ascertain how value is created or perhaps co-created between science communicators, given the co-creational emphasis in social marketing and innovation theory (Lee, Olson and Trimi, 2012; Lefebvre, 2012).

Table 4.2 Functions of Mixed-Method Designs

Function of Study	Purpose	Rationale
Triangulation	Seeks convergence, corroboration of results from the different methods	To increase the validity of constructs and inquiry results by counteracting or maximising the heterogeneity of irrelevant sources of variance attributable especially to inherent method bias, bias of substantive theory, biases of inquiry context
Complementarity	Seeks elaboration, enhancement, illustration, clarification of the results from one method with the results from another method	To increase the interpretability, meaningfulness, and validity of constructs and inquiry results by both capitalising on inherent method strengths and counteracting inherent biases in methods and other sources
Development	Seeks to use the results from one method to help develop or inform the other method, where development is broadly construed to include sampling and implementation, as well as measurement decisions	To increase the validity of constructs and inquiry results by capitalising on inherent method strengths
Initiation	Seeks the discovery of paradox and contradiction, new perspectives of frameworks, the recasting of questions or results from one method with questions or results from another method	To increase the depth and breadth of inquiry results and interpretations by analysing them from the different perspectives of different methods and paradigms
Expansion	Seeks to extend the breadth and range of inquiry by using different methods for different inquiry components	To increase the scope of inquiry by selecting methods most appropriate for multiple inquiry components

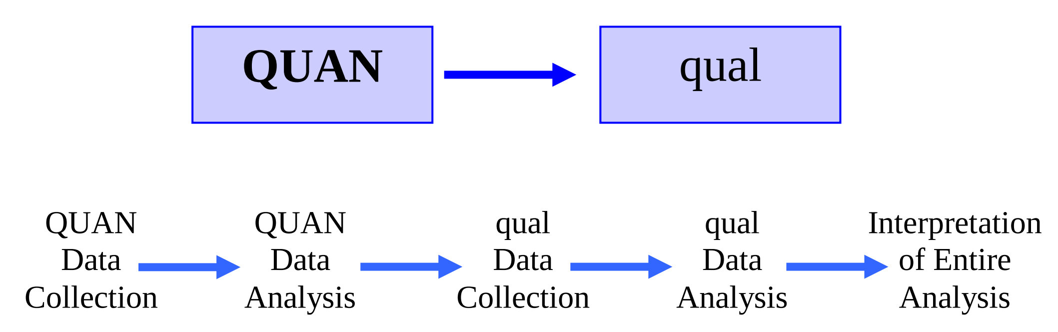
Source: Greene, Caracelli and Graham (1989, p.259)

In mixed method research, Denscombe (2008) discusses the relationship between quantitative and qualitative components and the differing views on how quantitative and qualitative research designs should be used and whether they can be integrated, combined, or used in tandem.

4.2.1 Research Designs in Mixed Method Research

According to Bryman and Bell (2007) quantitative research can facilitate qualitative research and vice versa qualitative research can facilitate quantitative research. There are two popularised strategies of inquiry in mixed methods research; sequential and concurrent (Creswell, 2009). Sequential designs begin with a collection of either qualitative or quantitative data in the initial stage, followed by the collection of the other data type during a second stage. Alternatively, concurrent designs involve the collection of both types of data during the same stage (Castro et al., 2010). This research employs a sequential research design and more specifically, a sequential explanatory method is used for data collection where the quantitative phase is followed by the qualitative phase, as illustrated in Figure 4.2.1

Figure 4.2.1 Sequential Explanatory Design



Source: Creswell (2009, p.209)

In explanatory sequential designs, priority is given to the quantitative strategy of inquiry and the two methods are integrated during the interpretation stage (Creswell et al., 2003). The advantages of a sequential explanatory research design purported by Ivankova, Creswell and Stick (2006) include straightforwardness and opportunities for the exploration of the quantitative results in more detail. Furthermore, sequential explanatory designs reflect complementarity, development and expansion as the qualitative phase to the research deepens the breadth and scope of the process indicator categories of knowledge, networks, intangibles and system dynamics.

Creswell et al. (2003) outline a time weakness to the sequential explanatory design as it can take a long period of time to complete the separate phases. However, Creswell et al., (2003) also contend that time becomes especially lengthy in a sequential process when both methods of inquiry are given equal priority. Within this study, priority is given to the quantitative phase which measures the eleven process indicators as identified at the end of chapter three which include knowledge transfer, generation and exchange; network involvement, position and ties, system dynamics and the intangible indicators of trust, commitment, learning and reciprocity. The quantitative phase is given priority because it illustrates how process indicators provide an understanding of the activities between science communicators in the ROI. The subsequent qualitative phase involves a detailed exploration of the process indicator categories among a few individuals and groups through value network analysis (Greene, Caracelli and Graham, 1989).

In sequential explanatory designs, the mixing of quantitative and qualitative strategies of inquiry strengthens a study because social phenomena are so complex that the combined use of methods are needed to best understand these complexities (Creswell et al., 2003). However, the combination of methods is not without its criticism as Denscombe (2008) identifies that questions have been raised about the viability of using a simple quantitative-qualitative dichotomy. Furthermore, Denscombe (2008, p.273) argues "that the distinction between the notions of quantitative and qualitative is not watertight and that any simple quantitative-qualitative distinction hardly does any justice to the variety of epistemological and ontological assumptions that underpin the term". Consequently, pragmatism has been regarded as the philosophical partner for mixed methods research.

4.2.2 Pragmatism as the Philosophical Partner for Mixed Methods Research

Pragmatism offers a set of assumptions about knowledge and inquiry that underpins the mixed methods approach and distinguishes it from purely quantitative and qualitative philosophies (Denscombe, 2008). According to Tashakkori and Teddlie (1998) the integration of quantitative and qualitative paradigms can declare a détente in the paradigm wars through the co-existence of both methodologies and their underlying paradigms.

Pragmatists emphasise the research problem and use all approaches available to understand the problem as opposed to focusing on methods (Creswell, 2009). Pragmatists are not committed to any one system of philosophy and reality as illustrated in Table 4.2.2, as researchers draw from both quantitative and qualitative assumptions when engaging in their research (Creswell, 2009). Pragmatists see a more instrumental relationship between paradigm and methods (Firestone, 1987). Furthermore, Johnson and Onwuegbuzie (2004) contend that pragmatism provides a workable solution for mixed method research as quantitative and qualitative methods, philosophies and insights fit together in practice.

Table 4.2.2 Pragmatism in Social Science Research Methodologies

	Qualitative Approach	**Quantitative Approach**	**Pragmatic Approach**
Connection of theory and data	Induction	Deduction	Abduction
Relationship to research process	Subjectivity	Objectivity	Intersubjectivity
Inference from data	Context	Generality	Transferability

Source: Morgan (2007, p.71)

Pragmatism guides this sequential explanatory study as the paradigm offers an alternative to the purist either/or choice between quantitative positivism and qualitative constructivism (Firestone, 1987; Wheeldon, 2010). Pragmatism is not confined to deductive reasoning to reach specific conclusions or inductive approaches that seek general conclusions. Biesta (2010) suggests that researchers should view pragmatism as a set of philosophical tools that can be used to address problems rather than being understood as a philosophical position among others. Pragmatists therefore follow a flexible approach in abduction which allows for tentative explanations to emerge throughout the research process (Wheeldon, 2010). Wheeldon (2010) suggests that:-

> *"By focusing on solving practical problems, the debates about the existence of objective truth or the value of subjective perceptions, can be usefully sidestepped. As such, pragmatists have no problem with asserting both that there is a single real world and that all individuals have their own unique interpretation of that world" (Wheeldon, 2010, p.88).*

Johnson and Onwuegbuzie (2004) argue that pragmatists reject dogmatism in social sciences research as a researcher's choice is not bound by purely quantitative or purely qualitative methods. Instead, a pragmatist embraces an expansive and creative form of research rather than a limiting form (Johnson and Onwuegbuzie, 2004). Johnson and Onwuegbuzie (2004) also suggest that a pragmatic approach to mixed methods research is inclusive, pluralistic and complementary.

The literature review within this study explored participation processes in science communication. The integration of science communication with social marketing and innovation theory led to the conceptualisation of four key process indicator categories for science communication, within which eleven process indicators emerged. Following the literature review, phases one and two of the sequential mixed method study are fruitfully mixed through a pragmatic approach of active and iterative processes which provide the best opportunities to answer the primary research question and secondary objectives (Johnson and Onwuegbuzie, 2004; Greene and Hall, 2010).

The first phase represents the priority phase of the sequential explanatory design where the process indicators are tested and measured through deductive reasoning (Bryman and Bell, 2007). However, purely deductive approaches limit research and rather than subscribing to only one method as a purist, pragmatists look to many approaches to answer complex phenomena (Firestone, 1987; Creswell, 2009). Triangulation is not appropriate to this sequential mixed method study because findings from the first phase might influence those from the second phase, thereby positively biasing any comparisons (Onwuegbuzie and Collins, 2007). Therefore, phase two pursues a developmental purpose, as the data findings from phase one are used to inform the qualitative component to the research. The qualitative component to this study allows the researcher to explore the process activities between science communicators in greater detail (Ivankova, Creswell and Stick, 2006).

In recent times, pragmatism has come under scrutiny by philosophers who maintain that "many come to pragmatism looking for a way to get around many traditional philosophical and ethical disputes" (Johnson and Onwuegbuzie, 2004, p.19). Furthermore, Bryman and Bell (2007, p.643) suggest that sequential explanatory quantitative and qualitative methods are not complementary as they "ignore the assumptions underlying research methods and transform qualitative inquiry into a procedural variation of quantitative inquiry". Nevertheless for mixed methods research, pragmatism opens the door to multiple methods, different worldviews and different assumptions, as well as different forms of data collection and analysis (Creswell, 2009).

Mixed methods research designs and mixed method paradigms also influence the sampling decisions of a study which are discussed next.

4.2.3 Mixed Methods Sampling

Onwuegbuzie and Collins (2007) suggest that sampling strategies are even more complex for research which employs a mixed methods approach, either sequentially or concurrently than sampling strategies for purely quantitative or qualitative studies. This complexity is heightened by the scant literature available to researchers regarding how to select appropriate sampling designs in mixed methods research (Collins, Onwuegbuzie and Jiao, 2006). Teddlie and Yu (2007) propose that mixed method sampling strategies use both probability and purposive sampling strategies. The incorporation of a probability sample increases external validity while purposive sampling increases transferability (Teddlie and Yu, 2007). This study employs both probability and purposive sampling strategies in phases two and three respectively.

The chosen unit of analysis for both phases of this study are science communicators in the Republic of Ireland (ROI). The Republic of Ireland was chosen as the definition for the sampling unit as this study has traced the periodisation of science in the ROI. Northern Ireland has not been included in the sampling unit as the Northern counties fall under a different jurisdiction for science policy coordination and governance. Furthermore, the aim of this research is not to generalise the findings to all science communicators on the Island of Ireland. Instead, this research seeks to measure and test the theoretical model of process indicators for science communication.

Probability sampling is used in the quantitative phase of the study where each science communicator has an equal chance of being included in the sample (Teddlie and Yu, 2007). Furthermore, the sampling unit of science communicators are stratified according to their roles in science communication including policy level, practice level and public level orientations. Bryman and Bell (2007, p.187) suggest that stratified random sampling ensures that the "resulting sample will be distributed in the same way as the population in terms of the stratifying criterion".

Purposive sampling is used in the qualitative phase to obtain deeper insights into the process activities among science communicators. According to Onwuegbuzie and Collins (2007) purposive sampling selects information rich participants. A purposive sample was employed for phase two as the groups and individuals were available and willing to participate in the study (Onwuegbuzie and Collins, 2007).

The mixed method sampling strategy in this study represents a nested relationship (Johnson and Onwuegbuzie, 2007; Onwuegbuzie and Collins, 2007). A nested relationship implies that the science communicators selected for the qualitative phase represent a subset of the science communicators chosen for the quantitative phase of investigation (Johnson and Onwuegbuzie, 2007; Onwuegbuzie and Collins, 2007).

The science communicators who were chosen to participate in this study derived from a sampling frame which was generated specifically for this research.

4.2.3.1 Sampling Frame and Sample Size

There was no direct sampling frame of science communicators in the ROI available, therefore an indirect yet comprehensive sampling frame was generated from various sources that were available to the researcher. These resources included:

- Delegates from the Annual Communicating Science, Technology, Engineering and Maths (STEM) Conferences (2009, 2010, 2011);
- Delegates from the Annual Atlantic Conferences on Science, Technology, Engineering and Maths Education (2009, 2010);
- Delegates from the Annual National Social Marketing Conferences (2009, 2010, 2011);
- Members of the Science Communicators Ireland Group on LinkedIn; and
- Website Searches.

In relation to delegate listings, the attendees of the annual social marketing conferences were already in the public domain as each year a list of the delegates and their email addresses were published in the conference packs. The attendees of the social marketing conference were relevant to this study as attendees spanned multiple domains of science such as the environment, heritage, local conservation, outreach and education. Regarding STEM conferences, the conference packs included a delegate listing however, email addresses were not included. The organising committees of the STEM conferences were contacted directly by the researcher to obtain access to the conference datasets. It was made very clear to the organising committees that the lists would only be used for the purposes of this study and under no circumstances would the datasets be used again without prior permission from the committees. In addition, the researcher also assured the conference organising committees that their respective datasets would not be shared with any other department within, or organisation outside of, the National University of Ireland Galway.

The researcher was already a member of the Science Communicators Ireland Group on LinkedIn and was connected to various members within the group. At the time the sampling frame was compiled, there were circa 600 members within the group. Although there was no direct access to email addresses, the researcher had direct and consented connections with group members of the Science Communicators Ireland group. Furthermore, the researcher had received datasets with permission from the group coordinator. The email addresses of the remaining members were identified through public searches on Google. In the case of thirty members identified on LinkedIn, no public email addresses were found and so these members were discarded from the study.

In total 932 science communicators were deemed eligible to participate in this study. This number was reached once the various datasets were amalgamated and duplicates were removed. The researcher also checked the details of participants to ensure useable email addresses had been given by the conference organising committees. The participant list includes policy makers, government agencies, regulators and local authorities who inform and contribute to science policy decisions. National education departments, science teachers, teachers associations, primary school science centres, education centres and lecturers from universities and institutes of technology were also included, given their roles in science education and curriculum assessment. Science media organisations, journalists and people from aquaria, museums, planetariums, heritage groups, cultural groups, conservationists, and organisations from industry were also included given their affiliations with the general public and society. The dataset compiled for this study is by no means a census of the science communication population but it does build on the work of Davison et al. (2008) who were the first group to comprehensively survey science outreach activities on the Island of Ireland where the data list consisted of 165 participants.

Sample size is an important consideration in mixed methods research as Onwuegbuzie and Collins (2007) suggest that the choice of sample size is as important as the choice of sampling scheme, because it also determines the appropriateness of particular statistical techniques and data analyses procedures. Furthermore, Onwuegbuzie and Collins (2007) argue against the classic dichotomy of large samples being associated with quantitative research and small samples being associated with qualitative research. At a minimum in quantitative correlation research designs, there should be 64 participants for one-tailed hypotheses and 82 participants for two-tailed hypotheses (Onwuegbuzie and Collins, 2007).

The sample population for this study is 932 participants. Malchimp (2012), states that the estimated open rate of educational surveys is 36.1% which leaves a potential sample size of 336 for the quantitative phase of this study. According to Onwuegbuzie and Collins (2007), phase one of this study needs to obtain a response rate of between 19% and 24.4% to satisfy the minimum sample size recommendations and manage for sampling frame error. In relation to a qualitative sample size, Onwuegbuzie and Collins (2007) determine that 12 participants are appropriate for interview methods. This research employs semi-structured interviews with groups and individuals during the qualitative phase, therefore, to satisfy the minimum sample size recommendation, the researcher must ensure that the purposive sample chosen from the sample population includes 12 participants (Onwuegbuzie and Collins, 2007).

Thus far, the above sections have elaborated upon the research design, paradigm and sampling strategies of this mixed methods research. The reminder of the chapter will examine the quantitative and qualitative data collection methods, instruments and analysis procedures.

4.3 Data Collection and Analysis: The Quantitative Phase

This sections details the quantitative phase to the study in terms of the data collection method, instrument, fieldwork and analysis procedures.

4.3.1 Data Collection Method

The process indicators which were developed and conceptualised through the integration of science communication with social marketing and innovation theory in the literature review are measured through a self-administered online survey. The rationale for using a quantitative online survey derives from the literature, as each of the authors of the adapted measurement scales in this study employed a survey methodology. Furthermore, the authors of the adapted measurement scales also used questionnaires as the research instrument, as shown in Appendix Two, justifying the use of a questionnaire as the research instrument in this study to answer the primary research question of *how process indicators contribute to the understanding of activities between science communicators in Ireland*.

4.3.1.1 Online Survey

Dillman (2007) believes that social science research is witnessing a profound transformation with the exponential growth and collection of survey data through self-administered electronic surveys by email and the web. Porter and Whitcomb (2003) also popularise web survey methodologies but the authors caution that they are not entirely clear if the techniques used to increase response rates in paper and telephone surveys directly transfer to web surveys. In conjunction with Porter and Whitcomb (2003), Millar and Dillman (2011) maintain that internet surveys are growing in popularity yet their response rates are typically lower than those of mail surveys. Bryman and Bell (2007) counter argue the position of Millar and Dillman (2011) recognising that although online surveys are in their infancy, there is evidence that online methods can increase response rates to postal questionnaires in a mixed mode collection strategy.

The most prevalent forms of online surveying are email surveys and web surveys (Bryman and Bell, 2007). This research makes use of a web survey as the participants are directed to a web site in order to answer the questionnaire.

The advantages to collecting data through web surveys are supported by Dillman (2007) who contends that the process of collecting data via electronic methods is more efficient than traditional methods such as post or face-to-face. These efficiencies include "the nearly complete elimination of paper, postage, mail out and data entry costs … In addition the time required for survey implementation can be reduced from weeks to days, or even hours" (Dillman, 2007, p.352). Online web surveys also exert advantages over email surveys in that a web survey can use a much wider variety of embellishments in appearance, can be sent over a secured server and provide quicker response rates and instantaneous feedback about a phenomenon of interest to the researcher (Bryman and Bell, 2007; Malhotra, 2010). Furthermore, Dillman (2007) suggests that web surveys provide more dynamic interaction between the respondent and the questionnaire than can be achieved in email or postal surveys.

However, web surveys are not without their limitations. Umbach (2004) raises concerns regarding error in web surveys, particularly non-response error which is introduced when respondents to a survey are different from those who did respond. According to Malhotra (2010) bias may also intervene during the web survey process when respondents choose to answer the survey more than once. Furthermore, Bryman and Bell (2007) argue that the creation of an aesthetically appealing survey requires a researcher to be highly sophisticated in the use of HTML or software packages that design questionnaires with features such as colour, drop-down boxes, radio buttons, filter questions and pictures.

4.3.2 Data Collection Instrument

This study uses an online questionnaire as the data collection instrument for the quantitative phase. According to Malhotra (2010, p.335) a questionnaire is "a formalised set of questions for obtaining information from respondents". Survey Monkey was chosen as the software package to design and compute the questionnaire because it has features such as colour, drop-down boxes, radio buttons and pictures. An online questionnaire serves three primary objectives set out by Malhotra (2010, p.335):-

1. *It must translate the information needed into a set of specific questions that the respondents can and will answer;*

2. *A questionnaire must uplift, motivate and encourage the respondent to become involved in the interview, to cooperate, and to complete the interview; and*
3. *A questionnaire should minimise response error.*

In lieu of the three objectives set out by Malhotra (2010), the process of designing the questionnaire becomes pivotal in answering how indicators contribute to the understanding of process activities between science communicators. Even though there are no formalised rules or scientific principles that guarantee an optimal or ideal questionnaire, questionnaire design either follows a deductive or inductive development pattern for item generation (Hinkin, 1995; 1998; Yi, 2009). The determination of survey questions for process indicators in this study follows a deductive scale development process which measures for construct validity, as the measures on a survey instrument must adequately represent the constructs under investigation (Hinkin, 1998).

4.3.2.1 Deductive Item Scale Selection Process

The determination of the individual questions and the appropriate selection of item scales for this questionnaire follow a deductive selection process which is sometimes referred to as logical partitioning or classification from above (Hinkin, 1998). Deductive item scale generation is appropriate as Chapter Three produced eleven construct definitions of the process indicators, producing eleven well-defined constructs. According to Yi (2009) well-defined constructs make it easier to develop good items which validate the scales. Deductive approaches are guided by the fact that the theoretical definitions of the constructs provide enough information to generate the initial sets of items (Hinkin, 1998).

Deductive approaches to scale development reproduce items that capture the phenomenon of interest to the researcher. Furthermore, if a deductive approach is executed properly, it will help to assure content validity in the final scales (Hinkin, 1998). The disadvantages of a deductive approach relate to time, as the process of sourcing, defining and producing construct definitions and scale items is time-consuming and requires the researcher to have sufficiently expert knowledge of the phenomenon under investigation (Hinkin, 1998).

In relation to the eleven process indicators of this study, a comparison of the authors of the construct definitions versus the authors of the appropriate measurement scales are illustrated in Table 4.3.2.1. Choi and Lee (2002) represent the only example where the authors scale items reflect their well-defined construct of knowledge generation. The scale produced by Choi and Lee (2002) was amended as appropriate to reflect the context of science communication and enhance the participant's ability to answer the knowledge generation questions.

Table 4.3.2.1 A Comparison of the Process Indicator Construct Definitions and Measurement Scales

Process Indicators	Construct Definitions	Adapted Measurement Scales
Knowledge Generation	Choi and Lee (2002)	Choi and Lee (2002)
Knowledge Transfer	Jacobson (2007)	Jerez-Gomez et al. (2005)
Knowledge Exchange	Prahalad and Ramaswamy (2004)	Chiva, Alegre and Lapiedra (2007)
Network Involvement	Gulati, Nohria and Zaheer (2000)	Hughes, Duane-Ireland and Morgan (2007)
Network Ties	Kramer and Wells (2005)	Tiwana (2008); Hansen (1999)
Network Position	Tsai (2001); Hardy, Philips and Lawrence (2003)	Reinholt, Pederson and Foss (2011)
Trust	Hunt and Morgan (1994)	Huff and Kelly (2003)
Commitment	Kramer and Wells (2005)	Cook and Wall (1980)
Learning	Hult and Ferrell (1997)	Janz and Prasarnphanich (2003)
Reciprocity	Chung, Singh and Lee (2000)	Mavondo and Rodrigo (2001)
Governance	Braun (2008)	Deshpande, Farley and Webster (1992); Moorman (1995); Moorman, Deshpande and Zaltman (1993)

The remaining authors of the ten process indicator constructs were not appropriate for the development of the measurement scales of the process indicators. Although the indicator measures underpin the theoretical base of the construct definitions, the process indicators do not meet the remaining requirements of Bearden and Netemeyer (1999) where measurement scales should be composed of multiple item questions; incorporate some scaling procedures throughout scale development; and estimates of validity and reliability exist.

In the instances of knowledge transfer, knowledge exchange, network involvement and governance, the authors of the respective construct definitions only produced theoretical papers with no empirical data collection methods or measurement scales for guidance. With no measurement scales readily available from the authors, a search of the science communication, social marketing and innovation literatures ensued, to source scales which adequately represented the themes within the well-defined process indicator constructs.

Kramer and Wells (2005) conducted qualitative case study research through their investigations of network ties and commitment and therefore, were not applicable to the deductive item scale generation.

Tsai (2001) made use of a single-item scale for network position, which was developed specifically within the context of who came to the population of interest for knowledge and who they went to in search of knowledge. The process indicators for this study, where possible, adapted multi-item scales as they capture more information than can be provided by a single-item scale (Bergkvist and Rossiter, 2007).

Hunt and Morgan (1994) conducted quantitative survey research for trust; however, the measurement scales used by the authors were not included in their research papers.

The measurement scale used by Hult and Ferrell (1997) to reflect learning was specifically designed for purchasing processes, which represented the phenomenon of interest under investigation. The scale items alongside the wording of the items were not appropriate to the context of science communication and therefore, the researcher had to look to the three streams of literature to identify a measurement scale which captured the well-defined construct of learning by Hult and Ferrell (1997).

In the final indicator of reciprocity, Chung, Singh and Lee (2000) did not employ the use of multiple-item likert scales in their data collection method. Instead, the authors used ratio scales. Ratio scales are not applicable to the context of reciprocity in this research as ratio scales would not sufficiently answer the primary research question of this study.

The measurement scale authors which have been chosen for this research, as illustrated in Figure 4.3.2.1 satisfy the requirements of Bearden and Netemeyer (1999). A methodological justification for each of the measurement scale authors can be found in Appendix Two. The structure, wording, order, form and layout of the chosen measurement scales in the questionnaire design process (Malhotra, 2010) are considered in the next section.

4.3.3 Questionnaire Design

Questionnaire design is an important consideration for two reasons. One reason is to reduce non-response error and the other is the reduction or the avoidance of measurement error (Dillman, 2007). According to Rattray and Jones (2007), the type of question, language used and order of items may all bias response. Therefore, careful consideration must be given to the order in which questions are presented and the ways in which the survey is designed to reduce non-response error. In recent times, researchers are increasingly faced with "decreasing response rates in surveys, as well as increased competition with marketers and spammers on the Internet, for the cooperation of respondents" (Porter and Whitcomb, 2003, p.579).

In response, Dillman (2007) states that it has been shown that respondent-friendly questionnaire design can improve response rates to a modest degree and reduce non-response error. Social science research has been guided by a conventional wisdom that believes for a sample to be representative, the survey's response rates must be high (Krosnick, 1999). Krosnick (1999) argues that when probability sampling is employed, as is the case in this research, it is no longer sensible to be guided by the mantra that lower response rates signal lower representation. In fact Krosnick (1999, p.540) suggests that recent research has shown that “surveys with very low response rates can be more accurate than surveys with much higher response rates”. Survey Monkey, an online software package was used to design and structure the online questionnaire. Survey Monkey enables the use of embellishments and sophisticated design features that are more interactive than traditional post and face-to-face survey methods. The use of colour in Survey Monkey makes it easier for the participant to navigate their way through a survey and measurement scale items, and answer categories were listed vertically as opposed to horizontally giving the respondent a sense of linear connection (Dillman, 2007). The incorporation of these design elements in the online survey manages for non-response error.

Each of the process indicator sections in the survey were presented on their own page with their own introduction. Furthermore, the layout and answering format for each question was clear and consistent throughout the survey. A progress bar was included to allow participant’s to view their progress as they worked their way through the survey and to avoid people quitting when they are only a few questions away from the end (Dillman, 2007). It was deemed appropriate by the researcher following the pretest stage to rename the intangible and system dynamic process sections to relational and structural processes, as the familiarity of the respondents with the previous terms would have been questionable in science communication and could have resulted in respondent confusion and increased response error. In addition to the practical design issues of the questionnaire, the researcher was also aware of ethical considerations surrounding the design and administration of an online survey in addition to the provision of incentives to participants.

4.3.3.1 Ethical Considerations

The researcher was aware of the ethical considerations of sending an online questionnaire to the science community. The legitimacy of the online questionnaire was maintained as the survey was sent using the researcher’s registered email address from the National University of Ireland, Galway. Furthermore, in the instruction section of the online survey, the researcher’s email address as well as the email address of the research supervisor was given to respondents if they sought further clarification, comments and questions. The university logo was also placed on the top left hand corner of every page of the survey acting as a reminder to the participants that the online survey was coming from a legitimate educational institution.

Anonymity and confidentiality were guaranteed by the researcher in the instruction section of the survey. The researcher also ensured that all data would be aggregated and atomised with no individual or organisation being identified at any point during the process. The last question on the survey gave respondents the option to receive a summary of the results by email which necessitated the provision of an email address. It was critical for the researcher to separate these contact details from the results of the survey to remain bound by the guarantees of anonymity and confidentiality. Furthermore, the researcher recognises the need to fulfil their obligation to all participants who provided email addresses for summary results upon completion of the study. Incentives provided in this study also create another ethical consideration for the researcher which will be discussed in greater detail in the next section.

4.3.3.2 Incentives

Incentives and more specifically financial incentives have received widespread attention in survey research (Dillman, 2007). According to Millar and Dillman (2011) research has shown that incentives have a considerable effect on response rates. This study incorporated an incentive that for each survey completed, 10cent would be donated to the Children’s Medical and Research Foundation in Crumlin Hospital. The amount to be donated was deemed appropriate as €100 had been set aside for the provision of an incentive. The choice of charity was influenced by the fact that the majority of charitable organisations relating to science communication were already included in the sampling frame and could not be chosen as the charity of choice. Dillman (2007) suggests that charitable donations may have no impact on response rates as this form of incentive does not invoke a feeling of reciprocation. However, the charity chosen is underpinned by science and its technological advancements and discoveries. The Children’s Medical and Research Foundation in

Crumlin Hospital is a children's charity where donations provide access to the very best treatments, facilities and equipment in medicine.

Ethically, it was essential for the researcher to follow through on their commitment to donate to the charity of choice to reciprocate the goodwill of the participants in choosing to complete the online survey. On the 4th of September, 2012 the researcher donated €30 to the Children's Medical and Research Foundation in Crumlin Hospital.

4.3.4 Fieldwork

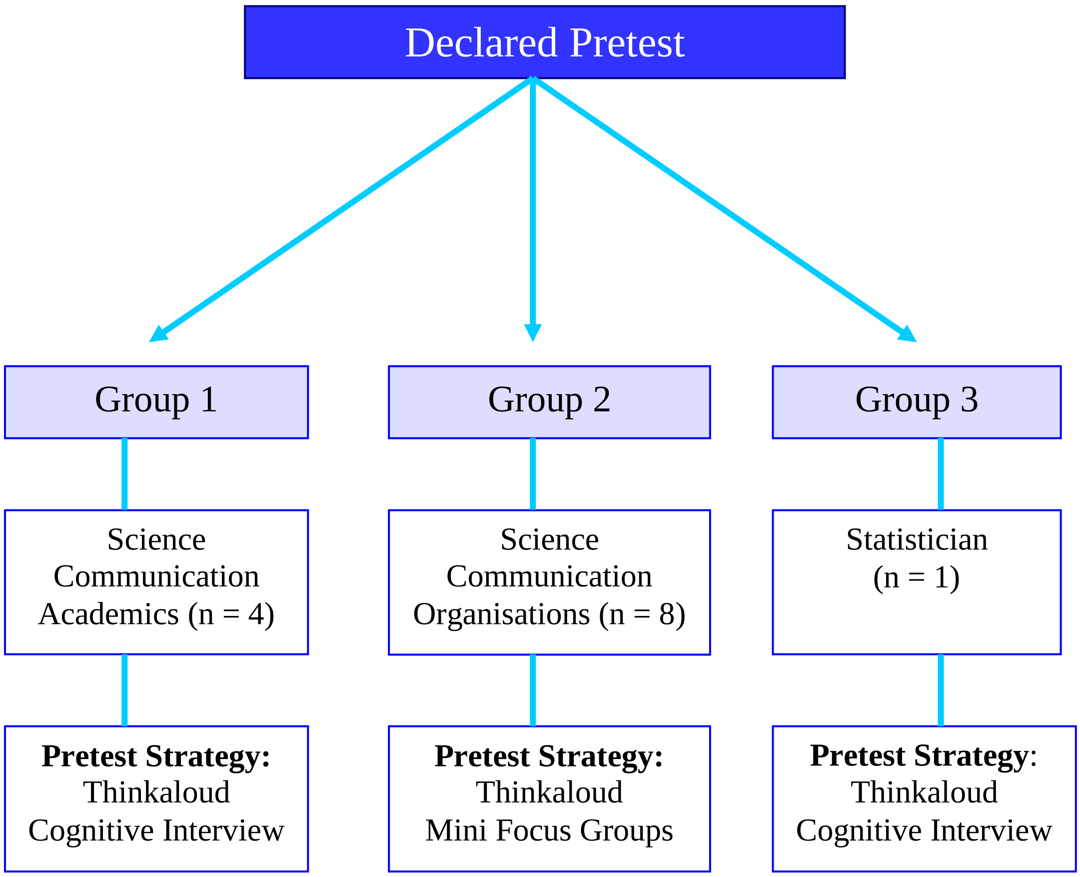
The questionnaire design, structure and format are pretested prior to its administration to test respondent comprehension, burden and interest. More specifically, the goals of this pretest stage are set out by Czaja (1998, p.53) which include:-

- *Do respondents have difficulty understanding words, terms or concepts?*
- *Is the sentence structure too complex? Do respondents understand the question, the task requires, and the answer format?*
- *Do respondents interpret the question as the researcher intends?*
- *Do respondents use different response categories or choices than those offered?*
- *Are respondents willing and able to perform the tasks required to provide accurate and complete answers?*
- *Are respondents attentive and interested in the questions?*

4.3.4.1 Pretest Procedure

In a pretest, it is important to get feedback from people with diverse expertise (Dillman, 2007). Dillman (2007) suggests that there is no finite or absolute number for pretesting in existence. In some studies, "feedback is solicited from dozens of individuals and divisions of an organisation … In other cases, one or two people have been able to provide all the help that seemed necessary" (Dillman, 2007, p.141). This research employed a declared pretest strategy with three groupings, as illustrated in Figure 4.3.4.1. The first grouping consisted of four academics that work or publish in the area of science communication. The second grouping consists of three science communication organisations that interact with the public and policy levels of science communication. The third grouping consisted of a statistician who assessed the measurement scales from a measurement and analysis perspective. The pretests took place in Galway and Dublin in the offices and locations of each of the pretest individuals and groups. In total, thirteen people were involved in the declared pretest stage of this study.

Figure 4.3.4.1 Declared Pretest Procedure



Each pretest candidate or group was invited to take part in the declared pretest via an email sent from the researcher. Once the candidate or group agreed to participate, the researcher set up a face to face meeting at a time, date and location that suited the pretest candidates.

The researcher adopted a thinkaloud conversational or cognitive interviewing strategy with the first and third groupings and a thinkaloud mini focus group strategy with the science communication organisations (Czaja, 1998; Krosnick, 1999; Dillman, 2007). Thinkaloud techniques allow the respondents to verbalise their thoughts and opinions as they attempt to answer the survey questions. The thinkaloud technique employed was concurrent as the researcher probed the respondents throughout the pretest process to assess the strengths and weaknesses of the survey questions and to address items which respondents found ambiguous or complex (Czaja, 1998). Furthermore, concurrent probing allows the researcher to get an understanding of how each question is being interpreted and whether the intent of the question is being realised (Dillman, 2007).

The researcher continued pretesting until saturation was reached after eight pretests in terms of the questions and items which reflected weaknesses and difficulties in comprehension. The thinkaloud cognitive interviews and focus groups employed in this pretest satisfied the six pretest goals set out by Czaja (1998) in section 4.3.4. The pretest stage identified the changes which needed to be made to the online questionnaire which are discussed in the next section.

4.3.5 Amendments to the Online Questionnaire

The pretest stage identified a number of changes which needed to be made to the structure and language of the online questionnaire to manage for measurement error (Dillman, 2007). This section details the amendments that were made to the instructions, demographic section, process indicator sections and the wrap up section.

4.3.5.1 Questionnaire Instructions

The instructions of the questionnaire contained all the relevant information but the order and wording of phrases needed amending. It was deemed confusing by pretest candidates to use the term ‘communication’ in the opening line – ‘*Welcome to this*

STEM Communication Study'. Therefore the opening line was changed to '*Welcome to this National STEM Study'*.

The contact details of the lead researcher and research supervisor for further questions and comments were moved from the middle of the instructions section to the end. In relation to the completion time, the pretest candidates advised that the completion time be reduced from 25-30 minutes to just 25 minutes. Pretest candidates advised the researcher that the inclusion of 30 minutes would immediately detract science communicators from answering the survey, especially when 25 minutes was calculated as the accurate timing for completion.

In the pretest, there were 8 points to remember in the instructions section for survey participants. These points were refined and restructured into 6 points as overlap and repetition were identified in the guaranteeing anonymity and confidentiality points. In addition, the author removed an item which informed participants that they can move back and forward between questions because arrows indicating '*Previous*' and '*Next*' were included at the bottom of each page of the online survey.

4.3.5.2 Demographic Section

The context of the questions in the demographic section was altered from the perspective of '*science outreach*' to '*science communication*' throughout. The pretest candidates felt that the interchangeable use of the terms created ambiguity for the respondent who may feel that certain questions are directed at science outreach officers and others for science communicators.

Furthermore, the demographic section was moved from the end of the survey to the beginning of the survey. The pretest candidates determined that each and every respondent who opened the survey could answer the demographic section in a matter of minutes because it included simple-to-answer questions. The candidates felt that leaving this section until the end could increase the ease of discarding the questionnaire (Dillman, 2007).

4.3.5.3 Process Indicator Sections

An introduction to each of the indicator sections was included following the pretests as candidates felt a line or two regarding the rationale for the knowledge, networking, relational and structural sections gave clarity and purpose to the respondent. This section describes the items in each of the process indicators and the amendments which were made to each process indicator question.

The measurement scales which were borrowed from authors in Table 4.3.2.1 included a mixture of likert scales ranging from 5 points to 7 points. The pretest candidates felt that 5 point scales should be used throughout the online questionnaire to ensure consistency. Furthermore, the candidates did not see the value of '*somewhat agree*' or '*somewhat disagree*' options, stating that they did not contribute significantly to the measurement scales. The '*neutral*' category in the 5 point scale was changed to '*N/A*' as pretest candidates felt that respondents may not have an opinion on some of the questions relating to knowledge, networks, relationships or structures.

Group two from the science communication industry in the declared pretest formulated four additional questions for networking processes which reflected how an organisation accesses a network. These inductive questions were added to the survey as candidates felt the identification of access points was a determinant of network involvement and a consequence of the role of a science communicator. Four nominal scales were developed with the science communication organisations exhausting all possible answers to questions 17-20 inclusively. In the happenstance that an option was not included, the researcher gave the option of '*Other*' to capture any category that wasn't included for the respondents.

The remainder of this section will describe the amendments made to the process indicator questions.

4.3.5.3.1 Knowledge Generation

The wording of some items in the knowledge generation scale required alteration to fit within the context of science communication. For example, '*well documented and stored*' replaced '*codified*' as each pretest candidate required an explanation of the term codified. Internal and external were also added to items 5 and 6 for clarity as seen in the final scale in the table below.

Table 4.3.5.3.1 Knowledge Generation Item Scales

Construct:	**Knowledge Generation**
Adapted from:	Choi and Lee (2002)
System	
Item Scale Selected	
Please rate how your organisation generates knowledge (5 point scale – Very Low to Very High) 1. Knowledge (know-how, technical skill or problem solving methods) are well documented and stored 2. Knowledge can be easily acquired through formal documents and manuals 3. Outcomes of projects and meetings are well documented 4. Knowledge is shared in codified forms like manuals or documents	
Human	
Item Scale Selected	
Please rate how your organisation generates knowledge (5 point scale – Very Low to Very High) 5. My knowledge can be easily acquired from internal experts and co-workers 6. It is easy to get face-to-face advice from external industry experts 7. Informal dialogues and meetings are used for knowledge sharing 8. Knowledge is acquired by one-to-one mentoring	
Validity measures: Reported Validity Measures	**Reliability Measures:** Cronbach's Alpha

4.3.5.3.2 Knowledge Transfer

In the knowledge transfer scale, all the items were deemed understandable within the context of science communication. One alteration was made in terms of the language used by Jerez-Gomez et al. (2005) where the word '*firm*' was replaced by '*organisation*' which resonates better with Irish science communicators. Item three was reverse-coded and is identifiable by the asterisk (*) below. The pretest candidates were not confused by the use of negative phrasing in this item.

Table 4.3.5.3.2 Knowledge Transfer Item Scale

Construct:	Knowledge Transfer
Adapted from:	Jerez-Gomez et al. (2005)
Item Scale Selected	
Please indicate your level of agreement with each of the following statements (5 point scale – Strongly Disagree to Strongly Agree) 1. Errors and failures are always discussed and analysed in this organisation 2. Employees have the chance to talk among themselves about new ideas, programmes and activities that might be of use to the organisation 3. In this organisation, teamwork is not the usual way to work (*) 4. The organisation has instruments (manuals, databases, files, organisational routines etc) that allow what has been learnt in past situations to remain valid, although the employees are no longer the same 5. People in my organisation receive support and encouragement when presenting new ideas 6. Initiatives often receive a favourable response in my organisation, so staff feel encouraged to generate new ideas	
Validity measures: Reported Validity Measures	**Reliability Measures:** Cronbach's Alpha

4.3.5.3.3 Knowledge Exchange

Minor amendments were made to the scale of knowledge exchange following the pretest. Item one was amended to include examples such as '*conferences and workshops*' to illustrate what the researcher meant by '*beyond the organisation*'. Item three was also amended to reflect STEM colleagues '*beyond our organisation*'. This change was made as pretest candidates interpreted the initial statement as STEM colleagues within the boundaries of an organisation.

The context of science communication was incorporated throughout the statements in the knowledge exchange scale as '*employees*' in the original items were replaced by '*STEM co-workers and colleagues*'. Cross-functional teamwork in item seven was reduced to just '*teamwork*' as pretest candidates had difficulty in the comprehension of cross-functional. Furthermore, it was felt that the placement of the term at the beginning of the sentence could deter respondents from answering the question and cause dropout rates to increase.

Table 4.3.5.3.3 Knowledge Exchange Item Scale

Construct:	**Knowledge Exchange**
Adapted from:	Chiva, Alegre and Lapiedra (2007)
Item Scale Selected	
Please indicate your level of agreement with each of the following statements (5 point scale – Strongly Disagree to Strongly Agree) 1. It is part of the work of all staff to educate ourselves on what is going on in STEM beyond our organisation (conferences, workshops, etc) 2. There are systems and procedures for collating and sharing information from outside the organisation 3. Staff are encouraged to interact with other STEM colleagues beyond our organisation 4. STEM co-workers are encouraged to communicate with one another 5. There is free and open communication within my organisational group of STEM colleagues 6. Managers facilitate free and open communication in this organisation 7. Teamwork is common practice in this organisation 8. Managers in this organisation frequently involve employees in important decisions 9. Organisational policies are significantly influenced by the view of employees 10. Staff feel involved in main organisational decisions	
Validity measures: Reported Validity Measures	**Reliability Measures:** Cronbach's Alpha

4.3.5.3.4 Network Involvement

The measurement scale by Hughes, Duane-Ireland and Morgan (2007) required two amendments to the phrasing of statements. The first amendment replaced '*business network*' organisations with '*STEM organisations*'. The second amendment replaced '*business network*' with '*STEM communication network*'. These amendments were deemed necessary as it created scales which reflected the context of science communication.

Table 4.3.5.3.4 Network Involvement Item Scale

Construct:	**Network Involvement**
Adapted from:	Hughes, Duane-Ireland and Morgan (2007)
Item Scale Selected	
Please indicate your level of agreement with each of the following statements (5 point scale – Strongly Disagree to Strongly Agree) 1. We regularly try to involve a number of other STEM organisations in the course of our business 2. We find it necessary to involve ourselves in a STEM communication network 3. We regularly attempt to obtain assistance from other outreach organisations available through a STEM communication network 4. We regularly participate in networks available through STEM outreach	
Validity measures: Reported Validity Measures	**Reliability Measures:** Cronbach's Alpha

4.3.5.3.5 Network Ties

The language used in the network ties statements by Tiwana (2008) and Hansen (1999) required modifications to reflect a science communication context. In the case of bridging ties, the term '*team*' was replaced with '*organisation*'. In the strong ties statements, '*co-workers*' replaced the terms '*team members*'.

The pretest candidates added an additional category of '*everyday*' to the weak ties item scale. The candidates felt that most science communicators interact with one another several times a day and the omission of the category would affect survey results. Upon deeper reflection, the category was added to the scale, as illustrated in the table on the next page.

Table 4.3.5.3.5 Network Ties Item Scales

Construct:	**Network Ties**
Bridging Ties	
Adapted from:	Tiwana (2008)
Item Scale Selected	
Please indicate your level of agreement with each of the following statements (5 point scale – Strongly Disagree to Strongly Agree) 1. Members of this organisation vary widely in their areas of expertise 2. Members of this organisation have a variety of different backgrounds and experiences 3. Members of this organisation have skills and abilities that complement each other	
Validity measures: Reported Validity Measures	**Reliability Measures:** Cronbach's Alpha
Strong Ties	
Adapted from:	Tiwana (2008)
Item Scale Selected	
Please indicate your level of agreement with each of the following statements (5 point scale – Strongly Disagree to Strongly Agree) 1. There is close, personal interaction among co-workers 2. There is high reciprocity among co-workers 3. There is mutual trust among co-workers 4. There is mutual respect among co-workers 5. There is personal friendship between co-workers	
Validity measures: Reported Validity Measures	**Reliability Measures:** Cronbach's Alpha
Weak Ties	
Adapted from:	Hansen (1999)
Item Scale Selected	
Please indicate how often STEM colleagues within your organisation interact with one another (on average over the past two years)? Everyday; once a day; twice a week; once a week; twice a month; once a month; once every 2nd month; once every 3 months	

4.3.5.3.6 Trust and Commitment

Huff and Kelly's (2003) item scale required a minor adjustment to the wording where '*subordinates*' were replaced with '*employees*'. In the same way, the statements which used '*firm*' from Cook and Wall's (1980) measurement scale were replaced with '*organisation*' as illustrated in the table below. The commitment scale made use of three reverse-coded items, which are identified in the table by an asterisk (*). The pretest candidates found no issues with the wording of these reversed items.

Table 4.3.5.3.6 Trust and Commitment Item Scales

<table>
<tr><td>Construct:</td><td colspan="2">Trust</td></tr>
<tr><td>Adapted from:</td><td colspan="2">Huff and Kelly (2003)</td></tr>
<tr><td colspan="3">Item Scale Selected</td></tr>
<tr><td colspan="3">Please indicate your level of agreement with each of the following statements
(5 point scale – Strongly Disagree to Strongly Agree)

1. There is a very high level of trust throughout this organisation
2. In this organisation employees have a great deal of trust for managers
3. If someone in this organisation makes a promise, others within this organisation will almost always trust that the person will do his or her best to keep the promise
4. Mangers in this organisation trust their employees to make good decisions</td></tr>
<tr><td colspan="2">Validity measures:
Reported Validity Measures</td><td>Reliability Measures:
Cronbach's Alpha</td></tr>
<tr><td>Construct:</td><td colspan="2">Commitment</td></tr>
<tr><td>Adapted from:</td><td colspan="2">Cook and Wall (1980)</td></tr>
<tr><td colspan="3">Item Scale Selected</td></tr>
<tr><td colspan="3">Please indicate your level of agreement with each of the following statements
(5 point scale – Strongly Disagree to Strongly Agree)

1. I am quite proud to be able to tell people who I work for
2. I sometimes feel like leaving this employment for good (*)
3. I'm not willing to put myself out just to help the organisation (*)
4. Even if the organisation were not doing well financially, I would be reluctant to change to another employer
5. I feel myself to be part of the organisation
6. In my work I like to feel I am making some effort, not just for myself but for the organisation as well
7. The offer of a bit more money with another employer would not seriously make me think of changing my job
8. I would not recommend a close friend to join our staff (*)
9. To know that my own work had made a contribution to the good of the organisation would please me</td></tr>
<tr><td colspan="2">Validity measures:
Reported Validity Measures</td><td>Reliability Measures:
Cronbach's Alpha</td></tr>
</table>

4.3.5.3.7 Learning

Again, wording in the learning measurement scale posed a problem. The pretest candidates understood the flow and sequence of questions in both promotive interaction and group processes, but the use of the word '*team*' throughout Janz and Prasarnphanich's (2003) measurement scale raised problems for the pretest candidates. As seen below '*co-workers'* is applied to the promotive interaction scale to make the statements easier to read and follow. In the group process item scales, '*team*' is replaced by '*group*' to reflect the interorganisational group context in science communication.

Table 4.3.5.3.7 Learning Item Scale

Construct:	**Learning**
Promotive Interaction	
Adapted from:	Janz and Prasarnphanich (2003)
Item Scale Selected	
Please indicate the level of truthfulness with each of the following statements (5 point scale – Completely True to Completely False) (*) 1. I like to share my ideas and work material with co-workers 2. I can learn important things from other co-workers 3. I like to help my co-workers 4. I like to share my ideas and work material with my co-workers when I think it will help them 5. It is a good idea for co-workers to help each other to learn 6. I like to co-operate with my co-workers 7. Members of my organisation learn a lot of important things from each other	
Group Process	
Adapted from:	Janz and Prasarnphanich (2003)
Item Scale Selected	
Please indicate your level of agreement with each of the following statements (5 point scale – Strongly Disagree to Strongly Agree) 1. We take the time as a group to examine areas in which we need more skill or experience 2. We rarely stop to consider how we can work better as a group (*) 3. We have recently discussed what we did right or wrong on a particular project or job	
Validity measures: Reported Validity Measures	**Reliability Measures:** Cronbach's Alpha

The answer structure to the promotive interaction measurement scale was reversed to a five point scale ranging from completely true to completely false, to identify respondents who exhibit response sets like acquiescence (Bryman and Bell, 2007). The pretest candidates noticed the structural change to the answer format and felt it was placed at a good point in the survey to refocus the respondents. The group process scale reverted back to the traditional form of a five point scale ranging from strongly disagree to strongly agree with one reverse-scored statement in item 2, which is identified by an asterisk in the table on the preceding page.

4.3.5.3.8 Reciprocity

The initial pretest with the academics from group one used a reciprocity measurement scale from Yau et al. (2000). The items revolved around the central statement '*if another STEM organisation helped me, I would help them back*'. Each of the pretest candidates found difficulties with the wording of the items and so the measurement scale was replaced. Mavondo and Rodrigo's (2001) measurement scale resonated better with science communicators and the pretest groups. In the measurement scale, the word '*partner*' was changed to '*STEM organisations*'.

Table 4.3.5.3.8 Reciprocity Item Scale

Construct:	**Reciprocity**
Adapted from:	Mavondo and Rodrigo (2001)
Item Scale Selected	
Please indicate your level of agreement with each of the following statements (5 point scale – Strongly Disagree to Strongly Agree) 1. Calling in favours is part of doing business 2. The practice of give and take of favours is a key part of the relationship between my organisation and other STEM organisations 3. I feel a sense of obligation to other STEM organisations for doing me a favour 4. I would feel embarrassed if I was unable to provide a requested favour to a particular STEM organisation 5. It is bad business not to return favours	
Validity measures: Reported Validity Measures	**Reliability Measures:** Cronbach's Alpha

4.3.5.3.9 System Dynamics

Initially, the system dynamics scale involved the allocation of points to each of the statements. The pretest candidates found this method at the end of the survey taxing and time consuming and suggested the use of a scale where single statements were chosen. The table below reflects only the keywords which were highlighted throughout each sentence in the final survey which can be seen in Appendix Three. The pretest candidates thought the allocation of capitals to the keywords was a good idea at the end of the survey as it gave respondents the option to choose between the keywords or seeking clarification through the complete statements.

Table 4.3.5.3.9 System Dynamics Item Scale

Construct:	**System Dynamics**
Adapted from:	Deshpande, Farley and Webster (1992); Moorman (1995) and Moorman, Deshpande and Zaltman (1993)
Item Scale Selected	
Please choose the single keyword which most closely describes ... **YOUR KIND OF ORGANISATION :** Personal; Dynamic and Entrepreneurial, Formalised and Structured; Production Oriented **LEADERSHIP STYLE:** Mentor; Entrepreneur; Co-ordinator; Producer **THE GLUE THAT HOLDS YOUR ORGANISATION TOGETHER:** Loyalty and Tradition; Commitment to Innovation and Development; Formal Rules and Policies; Tasks and Goal Accomplishment **WHAT IS IMPORTANT IN YOUR ORGANISATION:** Human Resources; Innovation; Stability; Competitive Advantage	

4.3.5.4 Wrap-Up Section

The pretest survey included two open-ended questions relating to the future of science communication. One question was phrased from the perspective of the organisation the respondent worked for and the second was phrased from the personal opinion of the respondent. During the pretest, these questions were mandatory. The pretest candidates felt that the questions should be optional and that the questions should be reduced to one single question. Upon reflection, the researcher condensed the questions into one single question and the answer drop-box was unlimited in terms of characters allowed. Pretest candidates felt that at this point, respondent's answers should not be restricted by character count. The purpose of this open-ended question was to compare the future direction of science communication in the literature against the future direction of science communication for science practitioners.

4.3.5.5 Summary of the Amendments

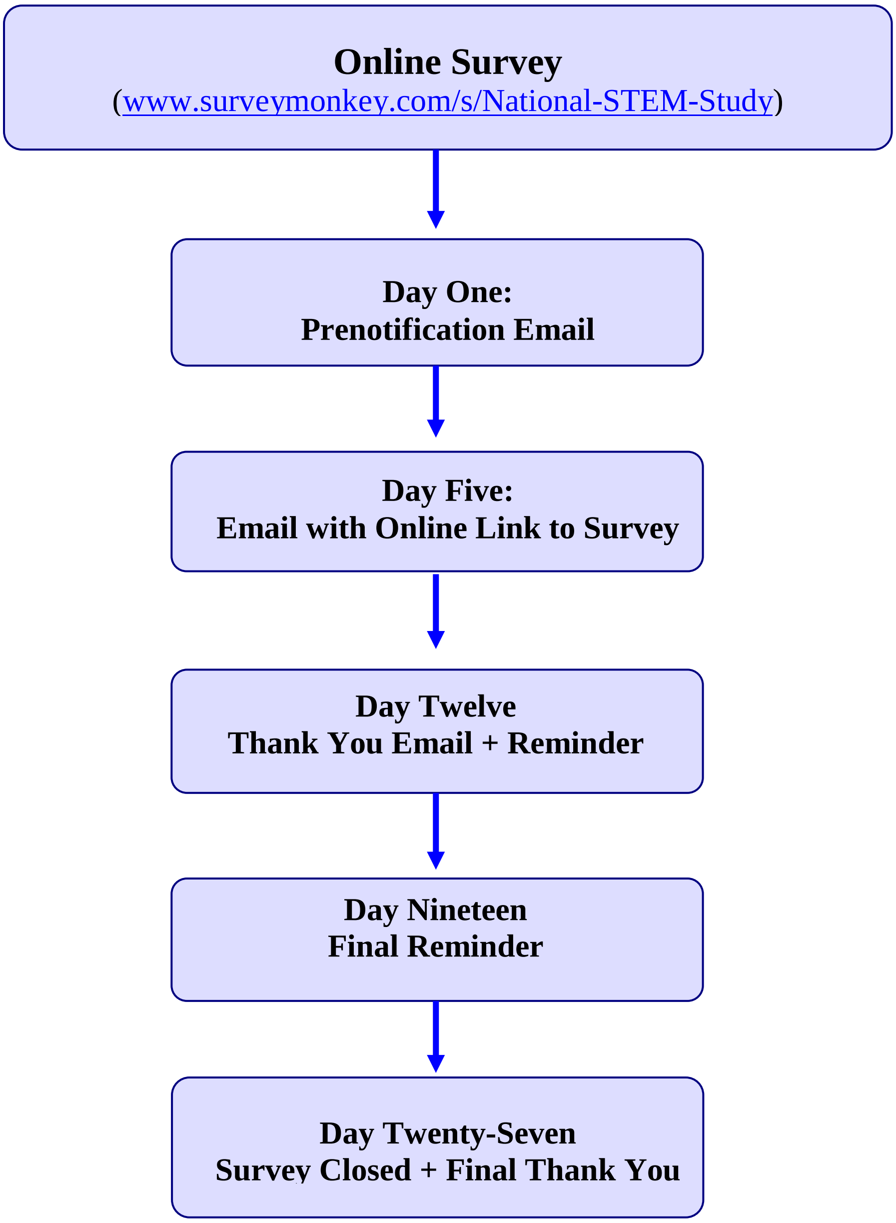
The amendments which were made to the questionnaire mainly involved changing the wording and language of the item scales to echo the everyday language used in science communication. Once the amendments were made, the items scales were more appropriate to the area of science communication, creating an online questionnaire that is easy to read, follow and answer. Amending online questionnaires after the pretest stage is an essential prerequisite to survey administration which is discussed in the next section.

4.3.6 Survey Administration

Survey administration for this online questionnaire followed Dillman's (2007) Tailored Design Method to reduce non response error, as illustrated in Figure 4.3.6. A prenotification email was sent to all respondents on day one, prior to the questionnaire. The aim of a prenotification is to authenticate the survey and allow participants to see that the follow up emails are not spam. The respondents were then emailed on day five with a link to the online survey and a brief email explaining what the survey is about and why a response is important (Dillman, 2007).

Over the course of two weeks, follow up emails are sent to all respondents thanking those of which have participated in the study and reminding those who have yet to complete the study that the closing deadline is approaching. A final contact is then made with all respondents on day twenty-seven indicating that the online questionnaire is closed and the researcher thanks all the respondents who took the time to complete the survey.

Figure 4.3.6 Dillman’s Tailored Design Method (2007)



Dillman (1991) suggests that a Tailored Design Method of survey implementation increases response rates. Kaplowitz, Hadlock and Levine (2004) argue that a tailored design method raises concerns for survey participants in terms of internet security and the receipt of spam or junk mail. Dillman (2007) counter argues stating that an interesting yet simple subject line in an email will prevent surveys from being directed into spam mail.

Umbach (2004) maintains that personalising emails can also increase response rates. Porter and Whitcomb (2003) argue that personalisation does not affect response rates and the use of names can also redirect the survey emails into spam folders. This survey did not make use of the personalisation of emails to manage for non-response error and to ensure that the survey links reached the respondent's inbox folders as opposed to their junk mail or spam folders.

4.3.7 Data Analysis Procedures

The statistical software package, SPSS, was used to analyse the quantitative data collected from the online questionnaires. The Survey Monkey package used in the design of the questionnaire was integrated with SPSS which enabled the direct transfer of data to SPSS for analysis and reduced the possibility of error on the part of the researcher from manual data entry. The researcher conducted a preliminary check on the data to check for missing data. Questionnaires which were incomplete and found to be missing more than 50% of data were eliminated from further analysis.

Preliminary data analysis began with descriptive statistics such as frequency counts expressed by the relative totals as well as cross-tabulations. The closed measurement scale data was analysed using exploratory factor analysis, correspondence analysis and regression. The final open-ended question on the survey used pattern matching to thematically analyse responses.

4.3.7.1 Exploratory Factor Analysis (EFA)

Exploratory factor analysis was used as a data reduction and summarisation technique for the process indicator measurement scales (Malhotra, 2010). The purpose of employing EFA was to identify underlying constructs in the data as well as to simply reduce the number of variables to a more manageable set (Churchill, 1979; Aaker et al., 2011). EFA was also employed to examine the relationship between variables and assess the internal consistency and unidimensionality of the process indicator measurement scales (Williams, Onsman and Brown, 2010). In addition, EFA was utilised to evaluate construct validity and provide construct validity evidence of the measurement scales (Williams, Onsman and Brown, 2010). In the quantitative phase of this research, the aim of EFA was not to test hypotheses or theories (Costello and Osborne, 2005) but to explore the amalgamated data set of process indicators. EFA is appropriate to this study, as the purpose of the quantitative research method is to explore the underlying factor structures of the process indicators; given it is the first time these indicators had been grouped together for empirical testing. Confirmatory factor analysis was not deemed appropriate for this study as there was no empirical model of process indicators to test. Although pre-existing individual measurement scales are available from science communication, social marketing and innovation theory, there is no one collective model of process indicators readily available to test hypotheses or theories in science communication.

4.3.7.2 Correspondence Analysis

Correspondence analysis was used as an exploratory technique for analysing the cross-classifications of the nominal scales in the survey, including STEM Area, STEM Sector, Organisational Type, Employment Status, Target Audience, Weak Ties and Network Access (Bartholomew et al., 2008). The primary goal of correspondence analysis in this research is to describe the "relationship between nominal variables in a correspondence table in a low dimensional space, while simultaneously describing the relationship between the categories for each variable" (Meulman and Heiser, 2004. p.59). Correspondence analysis also tests for independence via the chi square test and provides measures for association and tests of association (Meulman and Heiser, 2004).

4.3.7.3 Multiple Regression

Multiple regression analysis was utilised to determine if a relationship existed between the process indicators and determined the strength of the relationship between the process indicators (Malhotra, 2010). Another motivation underpinning regression analysis was to gain an understanding of the relationships between the process indicators as the process indicator model had not been previously measured or empirically tested in the literature.

4.3.7.4 Thematic Analysis

The final open-ended question in the survey was analysed through a thematic analysis. Respondent's answers were pattern matched by the researcher according to the predominant themes that emerged between the science communicators.

4.3.8 Validity and Reliability

Throughout the analysis procedures, the researcher is guided by two hallmarks of research; validity and reliability. The first measure of validity relates to content validity. Content validity refers to expert opinion concerning whether the content of the scale represents the proposed domains or concepts the questionnaire is intended to measure (Rattray and Jones, 2007). The pretesting stage with academics, industry and a statistician assessed the face validity of the scales to ensure the scale items adequately covered the entire domain of the construct being measured (Malhotra, 2010).

Construct validity, according to Churchill (1979) lies at the very heart of the scientific process and is most directly related to the question of what the instrument is measuring – what construct, trait, or concept underlies a person's score on a measure. The measurement scales for this study were borrowed through a deductive approach from the literatures of science communication, social marketing and innovation and satisfied construct validity, as there was a sound theory of the nature of the constructs being measured and how they related to other constructs (Malhotra, 2010). Construct validity is not sufficient by itself. Convergent and discriminant validity must also be demonstrated by correlating the measure with related and/or dissimilar measures (Rattray and Jones, 2007).

Convergent validity is a measure of construct validity that measures the extent to which the scale correlates positively with other measure of the same scale (Hinkin, 1998; Malhotra, 2010). Convergent validity is assessed through factor loadings where strong factor loadings that do not crossload indicate good convergent validity (Nguyen, 2010). According to Nguyen (2010), factor loadings which are less than

0.4 are considered weak while factor loadings greater than six are considered strong and statistically significant.

Discriminant validity is the extent to which a measure does not correlate with other constructs from which it is supposed to differ (Malhotra, 2010).Discriminant validity involves demonstrating a lack of correlation among differing constructs and factor correlations which are greater than 0.8 indicate poor discriminant validity (Malhotra, 2010; Nguyen, 2010).

Reliability should also be demonstrated in research. Reliability refers to the consistency and stability of findings that enables findings to be replicated (Burns and Burns, 2008). Coefficient alpha is the most common measure of reliability. Churchill (1979) suggests that coefficient alpha should be the first measure calculated to assess the quality of the instrument. However, Schmitt (1996) and Gerbing and Anderson (1988) argue that coefficient alpha is being misused by many researchers who treat the measure as synonymous with unidimensionality. Schmitt (1996) contends that internal consistency refers to the interrelatedness of a set of items, whereas homogeneity refers to the unidimensionality of the set of items. The level of adequacy for Cronbach’s alpha in this study was .70 as this is the conventional norm in social science research (Hulin, 2001).

The above section has described the quantitative data collection and analysis procedures employed in this study. The remainder of this chapter will examine the qualitative data collection and analysis phase of this research.

4.4 Data Collection and Analysis: The Qualitative Phase

This section details the qualitative phase to the study in terms of the data collection method, instrument, fieldwork and analysis procedures which sequentially follow the quantitative data collection and analysis phase.

4.4.1 Data Collection Method

The process indicators examined in the online questionnaire from phase one are explored in greater detail through semi-structured interviews to fulfil the sequential explanatory methodology of this research. Traditionally, VNA employs focus groups to analyse one purposeful activity among a network of organisations (Allee, 2009). VNA in this study was used to determine the networking activities of science communicators. Furthermore, VNA was employed to answer the primary research question of *how process indicators contribute to the understanding of activities between science communicators* and the secondary research objective of *how value is created between science communicators*. VNA goes beyond ‘who’ is involved in a network and effectively captures ‘what’ is exchanged and ‘how’ those exchanges take place in science communication. VNA effectively captures the dynamic and complex interplays between science communicators, providing powerful insights into the health and sustainability of the holistic system of science, whilst also providing a better understanding of the system parts in science communication.

4.4.1.1 Semi-Structured Interviews

Qualitative interviews vary a great deal according to the approach taken by the interviewer (Bryman and Bell, 2007). There are three prevalent categorisations of interviews which are unstructured, semi-structured and structured (Corbin and Morse, 2003; DiCicco-Bloom and Crabtree, 2006; Bryman and Bell, 2007). This research employs the use of a semi-structured interview technique, as illustrated in Table 4.4.1.1, where the researcher determined the structure of the interview but the participant controlled the amount of information provided (Corbin and Morse, 2003).

Semi-structured interviews are generally organised around a set of pre-determined open-ended questions (DiCicco-Bloom and Crabtree, 2006). Semi-structured interviews, unlike structured interviews are flexible and allow more questions to emerge throughout the course of the interview from the dialogue between the interviewer and the interviewee (DiCicco-Bloom and Crabtree, 2006).

Table 4.4.1.1 Interview Approaches

Dimensions	Unstructured	Semi-structured	Structured
Power relations	Agenda is set by the participant through the stories / events they choose to tell. Researcher may enhance the data collection process b y active listening and asking questions. P $\longrightarrow$ r	Researcher determines the structure of the interview and agenda through the questions asked. The participant controls the amount of information provided in the responses. R $\longrightarrow$ P	Researcher determines what information will be gathered. Participant may respond or refuse to respond. R $\longrightarrow$?
Control over interaction	Participant has the control over the pacing of the interview, what will be disclosed (the amount of detail, scope of the interview etc.), and the emotional intensity P $\longrightarrow$?	Participant may withhold important information because the relevant question was not asked, many answer in a perfunctory manner, or fully cooperate P $\longrightarrow$ r	Researcher has most of the control. The participant may only choose whether to respond (correctly or incorrectly) or to refuse to respond (i.e. to comply, sabotage, or not to play the game). R $\longrightarrow$ p
Direction of interaction	P $\longrightarrow$ r	R = P (Initially the researcher may control the direction. This shifts as the participant becomes more comfortable with the interview and commences narration).	R $\longrightarrow$ p (May be undermined by the participant by withholding information)

Note: Uppercase indicates dominance; arrow indicates direction; R=Researcher; P=Participant;

Source: Corbin and Morse (2003, p.340)

According to DiCicco-Bloom and Crabtree (2006), semi-structured in-depth interviews are the most widely used interviewing technique in qualitative research. Semi-structured interviews can take place with an individual or alternatively, small groups can also be employed. Semi-structured in-depth interviews take place once with the participant or participant group and can last from thirty minutes to several hours to complete (DiCicco-Bloom and Crabtree, 2006).

Semi-structured interviews have advantages over other methods of qualitative data collection in that the process is flexible. The main strength of semi-structured interview is in its ability to uncover more complete answers to questions that were asked in the structured questionnaire from phase one (Domegan and Fleming, 2007). Semi-structured interviews also benefit from a snowballing effect in that respondents control the amount of information they give, which can produce views and opinions of process indicators that were not reflected in the literature or from the survey findings.

Timing can be considered a weakness of interview techniques from the point of view of the researcher and the participant. Interviews can be physically exhausting for the interviewer (Domegan and Fleming, 2007) when the duration of an interviewer at one point in time can take multiple hours. On the part of the interviewee, it can be difficult to take the time to agree to an interview. However, Bryman and Bell (2007) contend that an interview is a two-way process where both parties gain something beneficial from the exchange process.

4.4.2 Qualitative Data Collection Instrument

This study uses an interview schedule as the data collection instrument for the qualitative phase of this research. The interview schedule for the semi-structured interviews followed an unconventional pattern as the interview schedule was predetermined by the analysis which was employed for the study. This study makes use of Value Network Analysis (VNA) where a value network can be defined as "any purposeful group of people or organisations creating social and economic good through complex dynamic exchanges of tangible and intangible value" (Allee, 2009, p.429). Value network analysis influenced the interview schedule as the author had to fulfil certain requirements during the data collection stage in order to use VNA at the analysis stage. VNA in this study maps out external-facing value networks between science communication organisations and other organisations in the STEM industry. VNA identifies the participants, transactions and deliverables in the STEM communication network. The elements of the map will be discussed in greater detail in the principal sections of the interview schedule.

The interview schedule was divided into seven principal sections, which were the main topics of discussion in each of the semi-structured in-depth interviews. There were no lists of specific questions on the interview schedule, as the schedule was designed to be used as a guide on what the discussion should cover. The interview schedule also contained probing mechanisms if the researcher felt that the interviewee was withholding information or was unclear about the direction of a particular section (DiCicco-Bloom and Crabtree, 2006). In all semi-structured in-depth interviews, each of the seven principal sections was discussed. A step-by-step guide to each of the seven principal sections and their inter-related activities in VNA for science communication are outlined in Table 4.4.2.

The first section relates to the introduction to the interview. The researcher engaged in conversation with each of the interviewees on their background and role in their respective science communication organisations. This technique was used in order to reduce the formality of a typical interview and to create a comfortable atmosphere with the participants in order to create an interactive dialogical style to the interview (DiCicco-Bloom and Crabtree, 2006). The researcher also explained what VNA was and the how the value network maps were going to be drawn out. Furthermore, the researcher clarified some ethical considerations of the mapping technique, including the recording of the interviews alongside the sharing and publication of the maps. In addition to their verbal consent, each interviewee was sent a written consent form following the interview to ensure their understanding of the guidelines of VNA.

Table 4.4.2 A Step-by-Step Guide to VNA in Science Communication

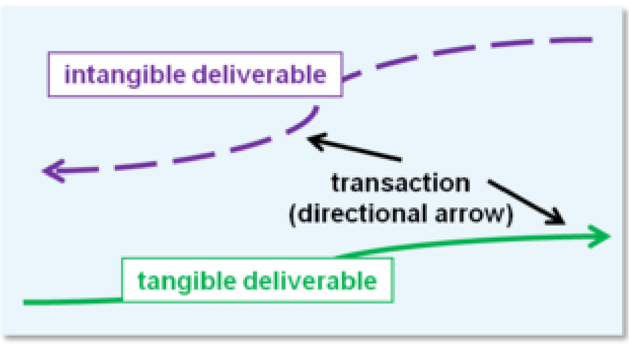
Step	Interview Schedule	Activities
Step 1	Introduction	♦ Introduce background to research ♦ Introduce background to VNA
Step 2	Identification of Role(s) and the Identification of External Facing Networks	♦ Identification of role(s) ♦ Identify networking partners / organisations ♦ Assign roles to networking partners / organisations
Step 3	Identification of Transactions and Deliverables	♦ Identification of transactions (directional arrows between networks) ♦ Identification of tangible deliverables (formal contract exchanges) ♦ Identification of intangible deliverables (market information and benefits)
Step 4	Exchange Analysis	♦ Analyse the flow to the way value moves through the system ♦ Analyse reciprocal links ♦ Analyse heart links ♦ Analyse weak links ♦ Analyse missing links ♦ Analyse dormant links
Step 5	Impact Analysis	♦ Analyse impact on intangible assets (e.g. human competence, internal structure, business relationships) ♦ Analyse the speed of transactions (high, medium, low). ♦ Analyse the channels through which deliverables are exchanged (e.g. face-to-face, telephone, email, online systems) ♦ Analyse the cost / risk to each deliverable ♦ Analyse the overall benefit to each deliverable ♦ Analyse the perceived value to the senders (i.e. participating organisations)
Step 6	Discussion relating to Trust in Science Communication	♦ Discuss the concept of trust or the '*crisis of trust*' in science communication in Ireland
Step 7	Wrap-up and Thank you	♦ Wrap-up the analysis ♦ Discuss follow-up emails with value network maps

Adapted from Allee (2008)

The second section of the interview schedule deals with the first step of the VNA map where participants in the external facing networks are identified. This step was assisted through the use of visual aids which illustrated to the interviewees what the maps consisted of and what their final map was going to look like. The map begins with the identification of the role of the interviewee. Allee (2008) suggests that organisations are discrete entities which consist of real people playing a variety of roles in different activities. Interviewees were asked to identify their role in science communication. In the event that the interviewee failed to consider an appropriate role, the researcher probed them with options. Furthermore, given the semi-structured nature to the interviews, the interviewees were free to choose one single role or multiple roles. Following the identification of the interviewee's role, all external science communication organisations in the STEM communication network were identified. The identification of the networks can take two forms; role-based where the roles are not job titles (e.g. coordinator, service provider, educator) or participant-based where the names of individuals, organisations or sectors are given.

The third section of the interview schedule identifies the transactions and deliverables in the participants value network map. Transactions or activities begin with one participant and end with another and are represented by direction lines in the value network map, as illustrated in Figure 4.4.2. Solid lines are "formal contract exchanges and dashed lines depict the intangible flows of market information and benefits" (Allee, 2008, p.14).

Figure 4.4.2 Transactions and Deliverables in Value Network Analysis



Source: Allee (2011)

Deliverables are the actual "things that move from one role to another" (Allee, 2008, p.14). The determination of the deliverables is guided by the knowledge and relational process indicator constructs. At this point of the semi-structured interviews, the interviewee controls the progress of the value network map through the identification of their transactions and deliverables.

The fourth section of the interview schedule relates to an exchange analysis. There are five probing questions which facilitate exchange analysis set out by Allee (2008, p.15) which include:-

- *Is there a coherent logic and flow to the way value moves through the system?*
- *Does the system have healthy exchanges of both tangibles and intangibles, or is one type of exchange more dominant?*
- *Is there an overall pattern of reciprocity? For example, is one of the roles extending several intangibles without receiving a similar return?*
- *Are there missing or dead links, weak and ineffective links, value dead ends, or bottlenecks?*
- *Is the whole system being optimised, or are some roles benefiting at the expense of others?*

The fifth section of the interview schedule involves an impact analysis. The researcher was in direct contact with Verna Allee, a specialist consultant and researcher in the area of VNA via Skype and emails. Verna Allee provided the researcher with a predetermined worksheet for impact analysis as seen in Table 4.4.2.0. The predetermined worksheet manages for interviewer error in VNA. Impact analysis assesses how specific value inputs are bringing value or benefit to each role, whilst also assessing the overall tangible and intangible cost/benefit for each value input (Allee, 2008).

Table 4.4.2.0 VNA Impact Analysis Worksheet

Transactions			Impact Analysis							
Deliverable	From	To	What activities generated	Impact on financial resources	Impact on intangible assets			Overall cost/risk	Overall benefit	Perceived value in view of recipient
					Human Compe-tence	Internal Structure	Business Relationships			+2 +1 Neutral -1 -2
Intangible										
Tangible										

The sixth section of the interview schedule revolved around the process indicator of trust where each interviewee was asked about trust in their STEM communication networks. This question was prompted by the science communication literature which declares an apparent '*crisis of trust'* in science communication (Sturgis and Allum, 2004; Bauer, Allum and Miller, 2007).

The seventh and final section to the interview schedule involved the wrap-up and thank you. The researcher also advised interviewees that follow up emails would be sent when the maps were created using specialist software. Once completed, the value network maps would be sent back to the interviewees for verification and amendments, if necessary.

4.4.3 Fieldwork

The value network mapping process was pretested with one group of five participants to assess the appropriateness and validity of the interview schedule. The researcher contacted the group by email and followed up with a telephone call at the request of the pretest group, to discuss the value mapping exercise in more detail and to arrange a face-to-face meeting at a time, date and location that suited the pretest candidates. The declared pretest was undertaken in Dublin, in the location of the science communication organisation.

The purpose of the declared pretest was to allow the pretest candidates to give their initial thoughts and reactions to the steps involved in VNA (Czaja, 1998).

Following the pretest, there were amendments made to the value network mapping process. VNA traditionally analyses one purposeful activity among a network of organisations (Allee, 2009). VNA in this study was employed to understand the multiple networking processes between organisations in the STEM communication industry, which necessitated two changes to the mapping technique. Firstly, the pretest group believed that the identification of the role of the interviewee was critical to the VNA process. However, because VNA in this study explores all the networks of a science communication organisation, the pretest candidates felt that clustering categories of science communicators together required a mixture of role-based and participant-based labels to their networks.

The second amendment to the VNA process relates to the deliverables. Allee (2008) designates two categories of deliverables; tangibles and intangibles. Tangible deliverables according to Allee (2008, p.7) are “contractual, mandated or expected” whereas intangible deliverables include “all unpaid or non-contractual activities that make things work smoothly and help build relationships”. The pretest group had no problem in discerning between tangible and intangible deliverables but the candidates found the identification of the intangible deliverables complex and ambiguous. The candidates felt that physical documents such as reports and sponsorships were not intangible deliverables. In order to overcome this ambiguity, the researcher divided intangibles into two categories; explicit intangible deliverables and implicit intangible deliverables. Explicit intangibles follow the conventional explanation in terms of anything you can physically feel, see or touch and implicit intangibles include “those little extras people do that help keep things running smoothly and build relationships” (Allee, 2008, p.11) such as goodwill, expertise etc. The pretest group found this clarification extremely beneficial to the process and as a result, this amendment was implemented for the remainder of the VNA mapping exercises.

Upon completion of the pretest, it was felt that the process of VNA was carried out successfully and following the inclusion of the amendments to the interview schedule, the researcher began the official mapping exercises with the purposive sample of science communicators.

4.4.4 Semi-Structured Interviews

A purposive sample was employed for phase two as the groups and individuals were available and willing to participate in the study (Onwuegbuzie and Collins, 2007). The purposive sample was chosen from the indirect sampling frame generated for phase one the online survey, where interviewees were selected on the basis that the researcher had met with them informally as key note speakers and delegates at the Annual Communicating STEM Conferences and the Annual Atlantic Conferences on Science, Technology, Engineering and Maths Education. In total, seven science communication organisations agreed to participate in the Value Network Analysis. Three of the semi-structured interviews were conducted with groups of two interviewees and four semi-structured interviews were conducted with individuals.

The researcher contacted each of the interviewees by email to arrange a face-to-face meeting. The semi-structured interviews took place in Galway and Dublin at the workplace locations of the interviewees. The researcher wanted the interviews to be convenient for the interviewees whilst also assuring the interviewees felt comfortable throughout the interview process. The interviews ranged from two-and-a-quarter hours to five-and-a-half hours to complete.

4.4.5 Data Analysis Procedures

Network analysis techniques are rising in popularity in social science research (Allee, 2009). Classic network analysis "provides powerful insights into patterns of human relationships and communication flows but it falls short in describing overall organisational performance. The empirical link between network patterns and value creation or realisation for the firm or the generation of economic and social good also has not been well demonstrated" (Allee, 2009, p.428). Social networks are a specific set of linkages among a defined set of individuals or groups (Tichy, Tushman and Fombrun, (1979) Social network analysis is a structural analysis technique which examines network ties and categorises network linkages where only one link is represented between actors (Allee, 2009). Allee (2009) argues that the empirical link between organisational level structures and firm level performance is under explored in social network analysis.

Alternatively, Allee (2008, p.11) contends that VNA does the following:-

- *Provides a fresh perspective for understanding value creating roles and relationships, both internal and external, upon which an organisation depends;*
- *Explains how to more effectively realise value for each role and how to utilise tangible and intangible assets for value creation; and*
- *Provides a systematic analysis of how one type of value is converted into another.*

VNA is suitable to this study as it provides the researcher with the opportunity to explore the process indicators from the literature review in greater detail, whilst also satisfying the secondary objective of analysing how value is created between science communicators.

Data collection and data analysis are conducted simultaneously in VNA. The data analysis procedures of value mapping, exchange analysis and impact analysis have been previously outlined in the above section through the discussion relating to the seven principle sections of the interview schedule. The analysis of the individual value network maps constitutes a reductionistic approach to VNA as the transactions, deliverables and exchanges of the individual STEM organisations are analysed and presented. The exchange and impact analyses constitute a collective and holistic analytical technique as the individual organisations are examined as one homogenous group constituting the system of science communication. Once the maps and analysis worksheets are completed within the interview, the researcher uses Visual Understanding Environment (VUE) software to create the illustrative value network maps. The information gathered on the impact analysis worksheets is also transferred to a Microsoft Excel workbook.

4.4.6 Validity and Reliability

Validity ensures that a researcher observes, identifies and measures what you say you are (Bryman and Bell, 2007). Validity in the qualitative stage was guided by the construct definitions of the process indicators from chapter three which were derived through deductive methods from the existing literatures in science communication, social marketing and innovation.

Credibility, which parallels internal validity, was achieved through respondent validation as value network maps were sent back to the interviewees for validation and where necessary amendments could be made to the maps (Bryman and Bell, 2007).

Transferability, which parallels external validity, ensures that the depth of information contained in the value network maps, exchange analysis and impact analysis are transferable to other contexts, or even in the same context at some other time. A thick description of the process indicator constructs and their measurement scales guiding this research were given by the researcher (Bryman and Bell, 2007). Additionally, the integration of three streams of literature in this study necessitated the transferability of data collection procedures and findings to other contexts.

Dependability like reliability is concerned with trustworthiness and internal consistency throughout the qualitative data collection process. Dependability also concerns the accuracy of the research process in terms of fieldwork notes, transcripts and data analysis decisions (Bryman and Bell, 2007).

Confirmability relates to the objectivity of the qualitative research. In VNA, there are predetermined schedules and analytical techniques to follow which ensured the objectivity of the data collection methods and eliminated biases. Furthermore, the mapping exercises were recorded to eliminate reporting biases as direct quotations from interviewees are used to support the findings and present theoretical justifications.

4.5 Chapter Summary

This chapter described how mixed method research approaches are emerging as the third methodological movement with its own worldview, vocabulary and techniques (Denscombe, 2008; Wheeldon, 2010). Mixed method approaches improve the accuracy of data and avoid biases intrinsic to single-method approaches (Denscombe, 2008). More specifically, the chapter described the explanatory sequential design of the study where priority was given to the quantitative phase and the qualitative phase investigated the process indicators in more depth. The two phases are then integrated during the interpretation stage (Creswell et al., 2003).

Pragmatism was chosen as the philosophical partner for this mixed method study. Pragmatists emphasise the research problem and use all approaches available to understand the problem as opposed to focusing on methods (Creswell, 2009). Pragmatists are not committed to any one system of philosophy and reality, as researchers draw from both quantitative and qualitative assumptions when engaging in their research (Creswell, 2009).

The quantitative and qualitative sections in this chapter describe the data collection methods and instruments employed in the study. Each method was rigorously pretested with science communicator groups and necessary amendments were made to the questionnaire items and interview schedules pertaining to the quantitative and qualitative methods respectively before implementation. Furthermore, the sections outline the data analysis procedures used to measure and test the process indicators for science communication.

The following chapter presents the analysis of the quantitative data collected through online questionnaires.

Chapter Five: Online Survey Findings and Analysis

5.0 Introduction

This chapter presents the findings from the quantitative phase of the research. More specifically, the purpose of this chapter is to present the quantitative findings that answered the primary research question of this study; '*how do process indicators contribute to the understanding of activities betweens science communicators in Ireland*' and the supporting secondary objectives of '*understanding the roles of science communicators in the process of science communication*' and '*determining how process activities differ, if at all, between science communicators with policy, practice and public orientations'*. The rationale for using a quantitative online survey derives from the literature, as the authors of the adapted measurement scales used survey methodologies with questionnaires as the research instrument. This chapter begins with a discussion of the respondent profile for the online survey, outlining the response rates as respondents moved from Section A to Section E in the online questionnaire. A descriptive summary of the role of science communicators in Ireland is then presented, as a secondary objective of this research is to *understand the roles of science communicators in the process of science communication***.** In addition, the number of years respondents have been working in the area of science communication is also presented.

Following this, the chapter continues with an analysis of the nominal variables through correspondence analysis, and the multiple response variables through frequency and cross tabulation tables. Exploratory factor analysis (EFA) identifies how many factors best explain the survey data, whilst also identifying the dimensionality of the process indicator measurement scales. Multiple regression analyses alongside a thematic analysis of the open-ended question on the online survey are also presented. Each section concludes with a discussion reflecting on how the findings of the online survey interconnect with the literature areas of science communication, social marketing and innovation theory. The chapter begins with an outline of the respondent profile to the online survey.

5.1 Respondent Profile

A total of 244 survey respondents participated in the online survey, producing an open rate of 72.6%. Of the 244 respondents, 135 surveys were deemed useable for further analysis producing a response rate of 40%, which co-aligns with Onwuegbuzie and Collin's (2007) minimum sample size requirements as previously outlined in chapter four. Of the original 244, twenty-three respondents dropped out after Question 2 on the demographics section, as seen in Table 5.1. A further thirty-seven respondents opted out after Section A in the survey. Twelve respondents left the survey after completing the knowledge process questions in Section B. Twenty-nine respondents chose to leave the survey after the networking questions in Section C and a further eight respondents left the survey after Section D, providing a total of 135 useable surveys for further analysis. Only one respondent dropped out in Section E providing 134 total responses to the online questionnaire. The final question on the survey asking about the future of STEM communication attracted ninety-eight respondents, producing a 74.8% response rate which the researcher views as significant given this was the last question on the online survey and it was left optional for science communicators to answer.

Table 5.1 Online Questionnaire Response Summary

Questionnaire Dropout Summary	Number of Respondents
Total Responses to National STEM Study Online Survey	244
Number who opted out after Question 2	23
Number who left the questionnaire after Section A: Demographics	37
Number who left the questionnaire after Section B: Knowledge Processes	12
Number who left the questionnaire after Section C: Networking Processes	29
Number who left the questionnaire after Section D: Relational Processes	8
Survey Response Rate	135
Number who left the questionnaire after Section E: Structural Processes	1
Total Survey Response Rate	134
Response Rate to Final Question (Optional)	98

5.1.1 Science Communication Roles

The science communication roles are reflective of the policy, practice and public levels in science communication. At the policy level, twenty-seven respondents actively influence science policy. In tandem with the coordination of policy, thirteen respondents influence the science education curriculum, producing a total of forty respondents working in the area of science policy and evaluation, as illustrated in Table 5.1.1. Thirty-three respondents operate at the practice level of science education and twenty-seven respondents engage with the public on science outreach. Thirty-five respondents fell into the 'other category' as these respondents felt they pursued multiple roles simultaneously, while for others they specifically outlined their roles as librarians, research coordinators and programme developers. Furthermore, respondents in the 'other' category designated the specific policy and education levels they work at such as energy policy, primary schools and secondary schools.

Table 5.1.1 Science Communication Roles

Role	Frequency	Percentage
Encouraging Science Education in Schools	33	24.4%
Engaging in Science Outreach with the Public	27	20.0%
Influencing the Science Education Curriculum	13	9.6%
Influencing Science Policy	27	20.0%
Other	35	25.9%

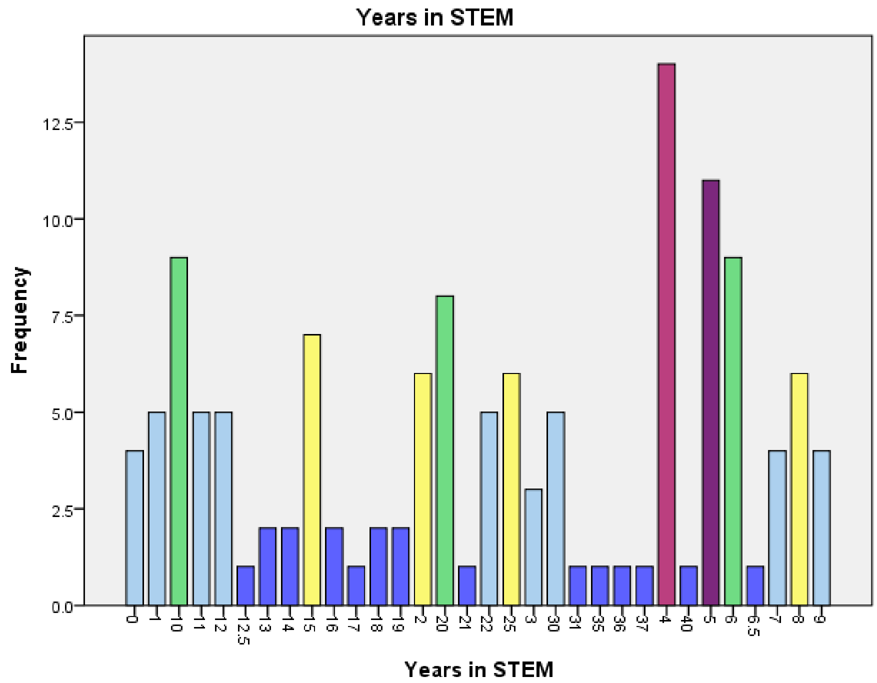
5.1.2 Years in STEM

Science communicators who work in STEM range from less than one year to forty years as illustrated in Figure 5.1.2. Four respondents have been working in STEM for less than a year while one respondent has been working in STEM for forty years.

Seventy-six respondents have been working in STEM between the periods of less than one year to ten years (0-10). Thirty-seven respondents fall into the period between eleven and twenty (11-20) years. Seventeen respondents have been working in the areas of STEM between twenty-one and thirty years (21-30), while five respondents have been working in STEM between thirty-one and forty years (31-40).

Fourteen respondents have been working in the area of STEM for four years while a total of thirty-four respondents have been working in the areas of STEM between four and six years (4-6).

Figure 5.1.2 Years in STEM



The next section of this chapter analyses the nominal responses of science communicators through correspondence and multiple response analysis.

5.2 Correspondence and Multiple Response Analysis

Correspondence analysis is an exploratory technique for analysing the relationship between two nominal variables graphically in a multi-dimensional space (Meulman and Heiser, 2004). Correspondence analysis aims to convert a table of numbers into a plot of points (Bartholomew et al., 2008). Correspondence analysis produces summary tables similar to crosstabulations; however, a crosstabulation does not always provide a clear picture of the nature of the relationship between two variables (Meulman and Heiser, 2004).

The nominal variables under investigation include STEM Area, STEM Sector, Organisational Type, Employment Status, Target Audience, Weak Ties and Network Access. Each of the nominal variables are analysed against STEM Role to satisfy the secondary objective of '*understanding the roles of science communicators in the process of science communication*' and another secondary objective of '*determining how process activities differ, if at all, between science communicators with policy, practice and public orientations'*.

The first step in the correspondence analysis is to perform a chi-squared test of association between the row and column variables. If a significant association is found, the nature of the association could be explored by examining row and/or column percentages (Bartholomew et al., 2008). The chi-squared association test in correspondence analysis is not a model fit statistic; it does not lend itself to comparing models with different variables as chi-square is often used. In correspondence analysis, the chi-square test of association tests the inertia value against zero, revealing relationships between variables that would not be detected through a pairwise test of association (Sourial et al., 2010). A significant association was found between STEM Role and two variables; namely STEM Area and Target Audience as seen in Table 5.2, indicating that total inertia is significantly different from zero.

Table 5.2 Chi-Squared Tests of Association

Nominal Variables	Chi Square Tests	Total Inertia Value
STEM Role * STEM Area	Chi square = 36.126; df = 24; sig= .053	The total inertia value **is** significantly different from zero
STEM Role * Sector	Chi square = 7.017; df = 12; sig= .856	The total inertia value is **not** significantly different from zero
STEM Role * Org. Type	Chi square = 49.393; df = 36; sig= .068	The total inertia value is **not** significantly different from zero
STEM Role * Employ. Status	Chi square = 12.527; df = 12; sig=.404	The total inertia value is **not** significantly different from zero
STEM Role * Target Audience	Chi square = 82.416; df = 32; sig=.000	The total inertia value **is** significantly different from zero
STEM Role * Weak Ties	Chi square = 19.200; df = 24; sig=.741	The total inertia value is **not** significantly different from zero
STEM Role * Net. Access	Chi square = 33.835; df = 32; sig=.379	The total inertia value is **not** significantly different from zero

In addition to the chi-squared test of association, the inertia levels of each of the two-way tables were taken into account. STEM Role and four variables (STEM Area; Organisational Type; Target Audience; Network Access) were found to have a strong and significant association when the inertia levels were greater than 0.2, as illustrated in Table 5.2.0. Inertia is used to describe the measure of scatter or variance in the row (or column) profiles about the centroid (Bartholomew et al., 2008).

Table 5.2.0 Inertia Levels

Nominal Variables	Inertia Level	
STEM Role * STEM Area	0.268	There **is** a strong and significant association
STEM Role * Sector	0.052	There **isn't** a strong and significant association
STEM Role * Org. Type	0.366	There **is** a strong and significant association
STEM Role * Employ. Status	0.093	There **isn't** a strong and significant association
STEM Role * Target Audience	0.610	There **is** a strong and significant association
STEM Role * Weak Ties	0.142	There **isn't** a strong and significant association
STEM Role * Net. Access	0.251	There **is** a strong and significant association

Correspondence analysis requires the total inertia value to be significantly different from zero as well as having a strong and significant association. The discussion within this section is limited to a correspondence analysis between STEM Role and STEM Area as well as STEM Role and Target Audience as these variables satisfied both the chi-squared test of association where significance levels were less than 0.05 and the inertia levels were greater than 0.2.

5.2.1 STEM Role and STEM Area

Correspondence analysis is a useful multivariate exploratory technique as it focuses mainly on how STEM Role and STEM Area correspond to one another and not whether there is a significant difference between these variables (Doey and Kurta, 2011). The relationship between STEM Role and STEM Area is significant at the 0.053 level and a chi-square value of 36.126, as displayed in Table 5.2.1. In the model, the total inertia (total variance explained) is 26.8%. This indicates for our model, knowing something about STEM Roles explains around 27% of something about STEM Area and vice versa. This association may be on the low side, but still highly significant as indicated by our chi-square statistic. Table 5.2.1 also displays the inertia on each dimension and the proportion of total inertia explained by the dimensions. The first dimension is dominant accounting for 48.7% of the total inertia. The second dimension explains 34.1% of inertia. Correspondence analysis solutions ideally represent the relationship between row (STEM Role) and column (STEM Area) variables in as few dimensions as possible (Meulman and Heiser, 2004). Together, dimensions one and two account for 82.8% of the total inertia. The coordinates on each dimension and the contribution to inertia of each dimension are shown for rows and columns respectively in Appendix Four.

Table 5.2.1 Summary Table for STEM Role and STEM Area

Dimension	Singular Value	Inertia	Chi Square	Sig.	Proportion of Inertia		Confidence Singular Value	
					Accounted for	Cumulative	Standard Deviation	Correlation 2
1	.361	.130			.487	.487	.067	.216
2	.302	.091			.341	.828	.077	
3	.187	.035			.131	.959		
4	.104	.011			.041	1.000		
Total		.268	36.126	.053[a]	1.000	1.000		

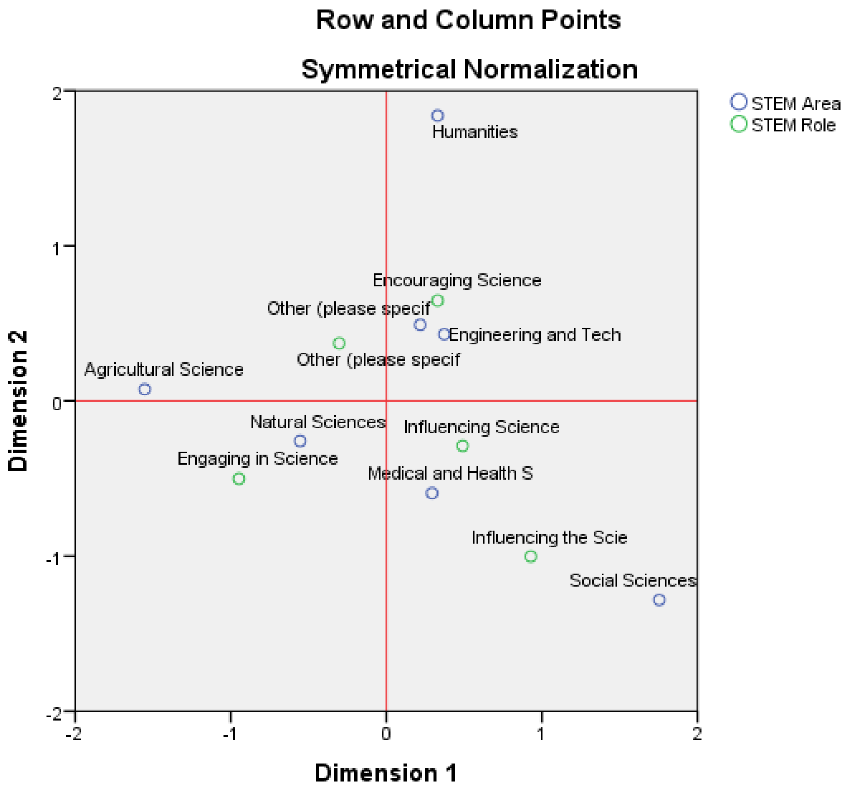
a. 24 degrees of freedom

The STEM roles with the largest contributions to inertia on dimension one are influencing the science curriculum (0.928) and influencing science policy (0.491) with positive coordinates, and engaging in science outreach with the public (-0.948) with negative coordinates. Thus, dimension one on the row point's contrasts policy level science from public level science. Turning to column points, social science (1.754) provide the largest contribution to inertia with positive coordinates on dimension one, while agricultural sciences (-1.553) and natural sciences (-.554) have negative coordinates on dimension one. Thus, dimension one on the column points contrasts the pure sciences from the non-pure sciences.

In relation to dimension two on the row points, the roles with the largest contributions to inertia are encouraging science education (0.647) with positive coordinates while influencing the science education curriculum (-1.003) has negative coordinates. Thus, dimension two on the row points contrasts those who work in education at the practice level from those who influence the education curriculum at policy levels. On the column points, the STEM area of humanities accounts for the largest contribution to inertia with a positive coordinate of 1.839. Social sciences (-1.282), the medical and health sciences (-.594) and the natural sciences (-0.258) have the largest contributions to inertia with negative coordinates. Therefore, the humanities are sharply contrasted with every other area in STEM.

In addition to the coordinates on each dimension, it is also important to consider the relative association between row and column categories by considering the location of row and column points jointly, as illustrated in the symmetrical bi-plot for the two-dimensional solution in Figure 5.2.1.

Figure 5.2.1 Two-dimensional representation of STEM Role and STEM Area



It is important to interpret the bi-plot from a relative association between the row and column categories, rather than an absolute level of association. In the symmetrical bi-plot, "we can only say that a pair of row-column categories that are close together are more strongly associated than a pair of categories that are further apart" (Bartholomew et al., 2008, p.95). Dimension one separates the agricultural and natural sciences from all other areas, while the second dimension separates the science education and 'other' roles from influential policy and public roles in STEM.

Symmetrical normalisation makes it easy to examine the relationship between STEM Role and STEM Area. In the lower left quadrant, natural sciences have a relative association in engaging with the public on science outreach. In the lower right quadrant, the medical and health sciences are associated with influencing science policy, while the social sciences are associated with informing the science education curriculum. In the upper left quadrant, the agricultural sciences are associated with all other roles in STEM, apart from the specific roles relating to policy, education and the public. In the upper right quadrant, the areas of engineering and technology as well as other STEM categories are relatively associated with encouraging science education, while the humanities are not strongly associated with any particular STEM role (but are far from influencing science policy).

5.2.2 STEM Role and Target Audience

The relationship between STEM role and Target Audience is highly significant at the .000 level, with an alpha of .05 and a chi-square value of 82.416. In the model, the total inertia (total variance explained) is 61 %. This indicates for our model, knowing something about STEM Roles explains around 61% of something about Target Audiences in STEM and vice versa. There is a strong and significant association in the inertia levels for this correspondence analysis. Table 5.2.2 also displays the inertia on each dimension and the proportion of total inertia explained by the dimensions. The first dimension is dominant accounting for 56.5% of the total inertia. The second dimension explains 21.2% of inertia. Correspondence analysis solutions ideally represent the relationship between row (STEM Role) and column (Target Audience) variables in as few dimensions as possible (Meulman and Heiser, 2004). Together, dimensions one and two account for 77.7% of the total inertia. Furthermore, two dimensions are sufficient for this correspondence model as dimension one accounted for 34.5% of inertia, while dimension two accounted for 13% of inertia, culminating to 47.5% of the total inertia levels. The coordinates on each dimension and the contribution to inertia of each dimension are shown for rows and columns respectively in Appendix Five.

Table 5.2.2 Summary Table for STEM Role and Target Audience

Dimension	Singular Value	Inertia	Chi Square	Sig.	Proportion of Inertia		Confidence Singular Value	
					Accounted for	Cumulative	Standard Deviation	Correlation 2
1	.587	.345			.565	.565	.055	.551
2	.360	.130			.212	.777	.067	
3	.307	.094			.155	.932		
4	.204	.042			.068	1.000		
Total		.610	82.416	.000[a]	1.000	1.000		

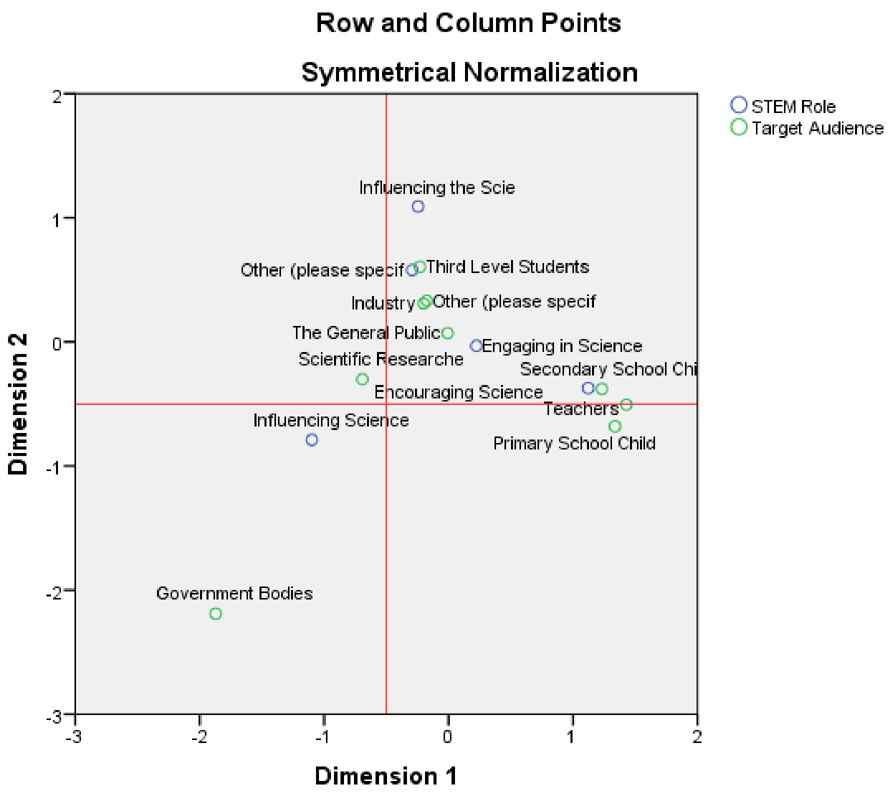
a. 36 degrees of freedom

The STEM roles with the largest contributions to inertia on dimension one are encouraging science education in schools (1.122) with positive coordinates, and influencing science policy (-1.099) with negative coordinates. Thus, dimension one on the row point's contrasts science education from science policy. Turning to column points, teachers (1.429) alongside primary school children (1.338) and secondary school children (1.233) provide the largest contributions to inertia with positive coordinates on dimension one, while government bodies (-1.871) have negative coordinates on dimension one. Thus, dimension one on the column points contrasts the education audiences of teachers and students from the policy audience of government bodies.

In relation to dimension two on the row points, the roles with the largest contributions to inertia are influencing the science education curriculum (1.091) with positive coordinates while influencing science policy (-0.789) has negative coordinates. Thus, dimension two on the row points contrasts those who work at the policy level in science, specifically distinguishing those who influence science policy coordination from those who contribute to science education curriculums. On the column points, third level students (0.605) and industry (.310) provide the largest contributions to inertia with positive coordinates. Government bodies (-2.190) provide the largest contribution with negative coordinates to inertia. The column points on dimension two contrast those who are pursuing careers in science from those who work at the policy level in science.

As previously identified in the preceding section, it is also important to consider the relative association between row and column categories by considering the location of row and column points jointly, as illustrated in the symmetrical bi-plot for the two-dimensional solution in Figure 5.2.2.

Figure 5.2.2 Two-dimensional representation of STEM Role and Target Audience



In the symmetrical bi-plot, dimension one separates government bodies from all other target audiences in STEM, while the second dimension separates the role of influencing science policy from all other roles in STEM.

Symmetrical normalisation again makes it easy to examine the relationship between STEM Role and Target Audience. In the lower left quadrant, government bodies have a relative association in influencing science policy. In the lower right quadrant, primary school children are the only target audience represented with no dominant STEM role present in the quadrant. However, given the close proximity of primary school children, teachers and secondary school children to the first dimension line, suggests that these variables are large and positive. In the upper left quadrant are the target audience of scientific researchers. The upper right quadrant contains the majority of coordinates describing the associations between row categories and column categories.

5.2.3 Multiple Response Analysis

Multiple response variables are interpreted through two types of analysis, which are frequency tables and crosstabulations. The multiple response categories in the National STEM Survey include STEM barriers and three network processes (network partnerships; purpose of involvement; form of contact).

Respondents identified that ‘encouraging a greater interest in STEM’ is the greatest barrier (n=49) in science communication. This barrier was particularly important to those who engage with the public through science outreach (n=17).

In terms of network partnerships, universities (n=105) and government bodies/state agencies (n=103) accounted for the most attractive groups to network with in science communication. Respondents with roles that involve engaging with the public through outreach identified the government to be the most important group to network with, while science educators found that it was important to network with universities.

The most frequent purposes for networking include keeping up to date with STEM activities and developments (n=87), access to STEM knowledge (n=86) and building connections with other STEM organisations (n=83). Furthermore, the most common form of contact between science communicators is online methods of communication (n=92). Online methods are especially prevalent to science communicators who have roles in STEM education and outreach. Further information such as the detailed frequency and crosstabulation tables used in the multiple response analysis are available in Appendix Six.

5.2.4 Structural Processes and STEM Roles

The roles of science communicators were also compared against the structural processes in science communication. According to Deshpande, Farley and Webster (1992), there are four types of organisational cultures in existence, namely clan, adhocracy, hierarchy and market. A total score was computed for each of the organisational cultures and a crosstabulation was performed against STEM Roles. The results, as displayed in Table 5.2.4 found that science educators associate best with an adhocracy culture, where creativity, flexibility, entrepreneurship and adaptability are important (Moorman, 1995). Science outreach providers are relatively associated with both a market culture that emphasises goal achievement, productivity and efficiency (Moorman, 1995), and also an adhocracy culture which values both flexibility and their competitive position in the external environment (Moorman, 1995). Respondents who work at the policy levels of science communication are associated most strongly with hierarchical cultures which emphasise “order, uniformity, efficiency, certainty, stability and control, reflecting internally oriented and formalised values” (Moorman, 1995, p.322).

Table 5.2.4 Crosstabulation of Structural Processes with STEM Roles

Structural Processes	Clan	Adhocracy	Hierarchy	Market
Role				
Encouraging Science Education	18	21	12	15
Engaging in Science Outreach	10	16	13	17
Influencing the Science Education Curriculum	6	4	10	6
Influencing Science Policy	8	13	22	16
Other	15	23	24	18

5.2.5 Discussion

The main finding from the correspondence analysis is that government bodies at the policy level of science are a distinct and separate group from the educators and outreach officers at the practice and public levels of science communication. This finding corroborates with the three levels of science communication from chapter two. The associated analyses between STEM role and STEM area produced results that segregate respondents who influence science policy and the education curriculum, from those who engage in public science outreach. Furthermore, correspondence analysis distinguishes respondents who work in the pure sciences from those who work in the non-pure sciences, supporting the definition of science purported by Weigold (2001) in chapter two.

The policy level in STEM co-aligns with the thinking of Lujan and Todt (2007) who suggest that the relationship between science and policy takes two forms; policy for science and science for policy. Science communication theorists such as Bradshaw and Borchers (2000) argue that a hierarchical gap exists between science and policy, which is also evidenced in the findings from correspondence analysis. The exploratory comparison between STEM role and target audience separated teachers and students of science education from government bodies, which further supports the policy, practice and public levels in science (Glicken, 1999; Weigold, 2001; Lujan and Todt, 2007).

The greatest barrier identified by the respondents was the ability to encourage a greater interest in STEM. Science policy documents are more concerned with science awareness and the stimulation of a greater understanding of science and its value to Irish society (Forfas, 2011). Alternatively, the literature in science communication is more concerned with greater literacy, understanding and participation in science (Stirling, 2008; Trench, 2008).

The crosstabulation procedure comparing the structural processes against STEM roles produced results which support the literature in science communication. Policy makers, government bodies and state agencies are associated most strongly with hierarchical organisations, whereas those who work at the midstream and downstream levels of science communication associate more with adhocracy and market cultures. Similar to the science communication literature, policy levels in STEM emphasise order, uniformity, efficiency, certainty, stability and control, (Moorman, 1995), whereas practitioners who mediate with students and society are more flexible, creative and responsive to their dynamic and changing environments (Moorman, 1995).

5.3 Exploratory Factor Analysis

EFA reduces data sets comprising of a large number of variables into a smaller number of factors to best explain the data (Burns and Burns, 2008). This exploratory technique succeeded in identifying the underlying factor structures within the process indicator measurement scales. Factor analysis only analyses shared variance which sets it apart from principal component analysis. Principal components analysis does not discriminate between shared and unique variance, which can produce inflated values of variance accounted for by the components (Costello and Osborne, 2005). Alternatively, factor analysis avoids the inflation of estimates of variance accounted for, since it only analyses shared variance (Costello and Osborne, 2005). EFA was employed in this study as a data reduction or simplification technique (Burns and Burns, 2008).

The first step in EFA is to determine the factor extraction method. According to Costello and Osborne (2005, p.2) "if data are relatively normally distributed, maximum likelihood is the best choice because it allows for the computation of a wide range of indexes of the goodness of fit of the model [and] permits statistical significance testing of factor loadings and correlations among factors and the computation of confidence intervals". Costello and Osborne (2005) advocate that when normality has been severely violated that principal axis factors is appropriate. The process indicator measurement scales displayed patterns of normal distribution and hence, maximum likelihood was chosen as the extraction method for this study.

Prior to conducting EFA, the reliability of the measurement scales was tested. Cronbach's alpha was chosen as the method to measure the internal consistency of the measurement scales. Each of the process indicator measurement scales satisfied Cronbach's alpha minimum acceptability of 0.7, as illustrated in Table 5.3. Furthermore, split-half and odd-even split-half reliability methods were conducted on the measurement scales with an even number of items. Knowledge generation produced a reliability score of less than 0.7 in the split-half method; however, reliability for knowledge generation in the odd-even split-half method produced a level of 0.832. Odd-even split-half reliability is outlined as a more commonly accepted method over split-half reliability by Burns and Burns (2008), as it not good practice to correlate the first half of a test with the second half as this can provide scope for error.

Table 5.3 Reliability and Item Validity of Measurement Scales

Measure Single Factors	Item	Reliability (Cronbach alpha)	Reliability (Split-half)	Reliability (Odd-Even Split Half)	Item Validity (correlation of item with total score-item)
Knowledge Processes					
Knowledge Generation	8	0.789	0.636	0.832	0.584; 0.564; 0.536; 0.686; 0.438; 0.372; 0.427; 0.346
Knowledge Transfer	6	0.860	0.829	0.877	0.576; 0.605; 0.535; 0.625; 0.782; 0.780
Knowledge Exchange	10	0.903	0.786	0.918	0.403; 0.569; 0.700; 0.656; 0.716; 0.795; 0.650; 0.700; 0.702; 0.687
Network Processes					
Network Involvement	4	0.875	0.849	0.874	0.632; 0.771; 0.803; 0.719
Bridging Ties	3	0.845			0.727; 0.811; 0.613
Strong Ties	5	0.945			0.830; 0.832; 0.928; 0.865; 0.793
Relational Processes					
Trust	4	0.919	0.920	0.914	0.859; 0.810; 0.771; 0.817
Commitment	9	0.862			0.635; 0.589; 0.526; 0.676; 0.726; 0.580; 0.601; 0.438; 0.537
Learning – Promotive Interaction	7	0.943			0.775; 0.843; 0.868; 0.813; 0.815; 0.896; 0.652
Learning – Group Processes	3	0.737			0.695; 0.458; 0.531
Reciprocity	5	0.865			0.638; 0.727; 0.689; 0.635; 0.742

EFA was employed to test the dimensionality of the process indicator measurement scales. EFA identified that six of the constructs were unidimensional including knowledge transfer, network involvement, bridging ties, strong ties, trust and reciprocity. Four of the process indicator constructs were multidimensional loading on two factors. These multidimensional constructs are knowledge generation, knowledge exchange, commitment and learning. A summary of the process indicator constructs which underwent maximum likelihood extraction and their resulting factor scores and labels are available in Table 5.3.0. Appendix Seven provides additional information on the unidimensional and multidimensional indicator constructs and their respective factor scores. In addition, the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity results are also presented to reinforce the suitability of the respondent data for EFA.

Table 5.3.0 Summary of Factor Dimensionality

Indicator Constructs	Extraction Method	Number of Factors	Multidimensional Factor Labels
Knowledge Generation	Maximum Likelihood	2	System Capital Human Capital
Knowledge Transfer	Maximum Likelihood	1	
Knowledge Exchange	Maximum Likelihood	2	Interactive Communication Internal Interaction
Network Involvement	Maximum Likelihood	1	
Bridging Ties	Maximum Likelihood	1	
Strong Ties	Maximum Likelihood	1	
Trust	Maximum Likelihood	1	
Commitment	Maximum Likelihood	2	Loyalty Organisational Involvement
Learning	Maximum Likelihood	2	Promotive Interaction Group Processes
Reciprocity	Maximum Likelihood	1	

The remainder of this section analyses the multidimensional constructs of knowledge generation, knowledge exchange, commitment and learning, assessing the factor loadings of each of the constructs on their respective factors.

5.3.1 Knowledge Generation

A factor analysis with subsequent rotation (Varimax) was conducted on eight items of the knowledge generation process indicator. Both the KMO and Bartlett's tests produced criteria that supported the application of EFA. Following rotation, knowledge generation loaded on two factors. Four of the eight statements loaded on factor one and the remaining four statements loaded on factor 2, as displayed in Table 5.3.1. All factor loadings for knowledge generation were above the 0.4 threshold with the exception of one statement. It was not necessary to delete item six as it was measuring knowledge acquired from external industry experts as opposed to internal experts as item five measured for knowledge generation.

Table 5.3.1 Knowledge Generation Factor Scores

Factor	Items	Label
Factor 1	Knowledge (know-how, technical skill or problem solving methods) are well documented and stored	System Capital
	Knowledge can be easily acquired through formal documents and manuals	System Capital
	Outcomes of projects and meetings are well documented	System Capital
	Knowledge is shared in codified forms like manuals or documents	System Capital
Factor 2	My knowledge can be easily acquired from internal experts and co-workers	Human Capital
	It is easy to get face-to-face advice from external industry experts	Human Capital
	Informal dialogues and meetings are used for knowledge sharing	Human Capital
	Knowledge is acquired by one-to-one mentoring	Human Capital

Following rotation, factor one was loaded on four items that reflected systems capital and accounted for 27.1% of the variance. The item that loaded the strongest on factor one was item two (0.712); ‘knowledge can be easily acquired through formal documents and manuals’. Collectively, the four items measure how knowledge is generated within a system through formal procedures and methods. This factor co-aligns with the literature of Choi and Lee (2002) who deconstruct knowledge generation into two categories; system and human capital knowledge generation.

Factor two loaded on four items that reflect human capital and accounted for 15.2% of the variance. The item that loaded the most on factor two was number seven (0.671) which stated that ‘informal dialogues and meetings are used for knowledge sharing’. Human capital was deemed appropriate as the factor label as it was also used by Choi and Lee (2002) in the innovation literature. Furthermore, human and systems capital reflect the theoretical concepts of tacit and explicit knowledge which are well articulated by Katsamakas (2007) in chapter three.

5.3.2 Knowledge Exchange

EFA with subsequent rotation (Varimax) was conducted on ten items of the knowledge exchange process indicator. The multidimensional construct of knowledge exchange satisfied both the KMO and Bartlett's tests criteria. Following rotation, knowledge exchange loaded on two factors. Six of the ten statements loaded on factor one and the remaining four statements loaded on factor 2, as displayed in Table 5.3.2. All factor loadings for knowledge exchange were above the 0.45 level.

Table 5.3.2 Knowledge Exchange Factor Scores

Factor	Items	Label
Factor 2	It is part of the work of all staff to educate ourselves on what is going on in STEM beyond our organisation (conferences, workshops, etc)	Interactive Communication
	There are systems and procedures for collating and sharing information from outside the organisation	Interactive Communication
	Staff are encouraged to interact with other STEM colleagues beyond our organisation	Interactive Communication
	STEM co-workers are encouraged to communicate with one another	Interactive Communication
	There is free and open communication within my organisational group of STEM colleagues	Interactive Communication
	Managers facilitate free and open communication in this organisation	Interactive Communication
Factor 1	Teamwork is common practice in this organisation	Internal Interaction
	Managers in this organisation frequently involve employees in important decisions	Internal Interaction
	Organisational policies are significantly influenced by the view of employees	Internal Interaction
	Staff feel involved in main organisational decisions	Internal Interaction

Following rotation, factor one loaded on four items that reflect internal interaction and accounted for 30.5% of the variance. The items that loaded the strongest on factor one was item nine (0.881); 'organisational policies are significantly influenced by the view of employees' and item ten 'staff feel involved in main organisational decisions'. Collectively, the four items measure how science communicators interact within the boundaries of their internal organisations. This factor co-aligns with, and reflects the interactive and dialogical nature to communication in social marketing, science communication and innovation theory.

Factor two loaded on six items that reflected interactive communication and accounted for 30.4% of the variance. The items which loaded the strongest on factor two were item three (0.760); 'staff are encouraged to interact with other STEM colleagues beyond our organisation' and item four 'STEM co-workers are encouraged to communicate with one another'. Collectively, the six items measure how science communicators interact with one another within organisations and beyond the boundaries of their internal environments. This factor reflects the interactive nature to communication, similar to total market approaches in social marketing, open and relational views in innovation theory and participation in science communication.

5.3.3 Commitment

EFA with subsequent rotation (Varimax) was also conducted on nine items of the commitment process indicator. The multidimensional construct of commitment produced a KMO level of 0.867 and the Bartlett's Test of Sphericity was significant at the .000 level. Following rotation, commitment loaded on two factors. Five of the nine statements loaded on factor one and the remaining four statements loaded on factor 2, as displayed in Table 5.3.3. All factor loadings for commitment were above 0.46.

Table 5.3.3 Commitment Factor Scores

Factor	Items	Label
Factor 1	I sometimes feel like leaving this employment for good	Loyalty
	I'm not willing to put myself out just to help the organisation	Loyalty
	Even if the organisation were not doing well financially, I would be reluctant to change to another employer	Loyalty
	The offer of a bit more money with another employer would not seriously make me think of changing my job	Loyalty
	I would not recommend a close friend to join our staff	Loyalty
Factor 2	I am quite proud to be able to tell people who I work for	Organisational Involvement
	I feel myself to be part of the organisation	Organisational Involvement
	In my work I like to feel I am making some effort, not just for myself but for the organisation as well	Organisational Involvement
	To know that my own work had made a contribution to the good of the organisation would please me	Organisational Involvement

Following rotation, factor one loaded on five items that reflect loyalty and accounted for 27.3% of the variance. The item that loaded the strongest on factor one was item two (0.856); 'I sometimes feel like leaving this employment for good'. Collectively, the five items measure how loyal science communicators are to their respective STEM organisations.

Factor two loaded on four items that reflected organisational involvement and accounted for 27.1% of the variance. The items which loaded the strongest on factor two were items six (0.784); 'in my work I like to feel I am making some effort, not just for myself but for the organisation as well' and nine 'to know that my own work had made a contribution to the good of the organisation would please me'. Collectively, the four items measure how science communicators are committed to their internal working environments. This factor co-aligns with the concept of mutual exchange in the literature as respondents move beyond the restricted tenets of self-interested exchange to mutually beneficial exchange relationships within an organisation.

5.3.4 Learning

Ten items of the learning process indicator underwent EFA with subsequent rotation (Varimax). The multidimensional construct of learning produced a KMO level of 0.875 and Bartlett's Test of Sphericity was also significant at the .000 level. Following rotation, learning loaded on two factors. Seven of the ten statements loaded on factor one and the remaining three statements loaded on factor 2, as displayed in Table 5.3.4. All factor loadings for learning were above 0.477.

Table 5.3.4 Learning Factor Scores

Factor	Items	Label
Factor 1	I like to share my ideas and work material with co-workers	Promotive Interaction
	I can learn important things from other co-workers	Promotive Interaction
	I like to help my co-workers	Promotive Interaction
	I like to share my ideas and work material with my co-workers when I think it will help them	Promotive Interaction
	It is a good idea for co-workers to help each other to learn	Promotive Interaction
	I like to co-operate with my co-workers	Promotive Interaction
	Members of my organisation learn a lot of important things from each other	Promotive Interaction
Factor 2	We take the time as a group to examine areas in which we need more skill or experience	Group Processes
	We rarely stop to consider how we can work better as a group (*)	Group Processes
	We have recently discussed what we did right or wrong on a particular project or job	Group Processes

Following rotation, factor one loaded on seven items that reflect promotive interaction and accounted for 48.2% of the variance. The item that loaded the strongest on factor one was item six (0.931); 'I like to co-operate with my co-workers'. Collectively, the seven items measure how science communicators actively promote learning within an organisation and encourage co-workers to share their ideas, skill sets and knowledge. Promotive interaction is supported in the literature as intra-cooperation, communication and participation is evident in the internal levels of innovation (Yang, Lin and Lin, 2010) and Nooteboom's (2000) team and firm levels of innovation.

Factor two loaded on three items that reflected group processes and accounted for 17.4% of the variance. The item which loaded the strongest on factor two was item eight (0.912); 'we take the time as a group to examine areas in which we need more skill or experience'. Collectively, the three items measure how science communicators come together as a team for reflection and evaluation. This factor co-aligns with the concept of double-loop and triple-loop learning from the literature where respondents evaluate how effective or ineffective work practices and strategies are and propose new ideas and alternative thinking as a group. Group processes eliminate power, control and coercion and emphasise creatively, flexibility and adaptability (Moorman, 1995).

5.3.5 Discussion

EFA was used in this study as an exploratory technique. The main finding from EFA is that knowledge generation, knowledge exchange, learning and commitment are complex constructs involving multiple dimensions. The aim of EFA was not to test hypotheses or theories (Costello and Osborne, 2005) but to explore the amalgamated data set of process indicators. EFA was appropriate to this study, as the purpose of the quantitative phase was to explore the underlying factor structures of the process indicators; given it was the first time these indicators had been grouped together for empirical testing. Confirmatory factor analysis was not deemed appropriate for this study as there was no empirical model of process indicators to test. Although pre-existing individual measurement scales were available from science communication, social marketing and innovation theory, there was no one collective model of process indicators readily available to test hypothesis or theories in science communication.

EFA identified the independent factors that were being measured by the multiple items of information gathered on the knowledge, relational and networking processes. EFA succeeded in identifying the underlying factor structures of the process indicator constructs, producing six unidimensional constructs and four multidimensional constructs. The multidimensional constructs produced a further eight factors consisting of human capital, system capital, interactive communication, internal interaction, loyalty, organisational involvement, promotive interactive and group processes.

The multidimensional constructs of knowledge generation outlined by Choi and Lee (2002) in the literature were reproduced in this study with the two factors being labelled human capital and system capital. In innovation theory, the levels and multi-dimensional view support the exploration and exploitation of two types of knowledge; explicit and tacit (Katsamakas, 2007). Explicit knowledge can be articulated and codified similar to systems capital in the form of documents and manuals. Alternatively, knowledge can be tacit and derived from cognitive components and mental models (Katsamakas, 2007) similar to that of human capital where knowledge resides with STEM workers in an organisation.

The learning concepts of promotive interaction and group processes from the literature were also supported in the findings. Commitment and knowledge exchange produced multidimensional constructs which were not previously identified in empirical research. However, the labels attached to the four factors of interactive communication; internal interaction; loyalty; and organisational involvement reflect the chosen definitions for learning and knowledge as outlined in chapter three. The next section performs a regression analysis on the each of the process indicator constructs.

5.4 Multiple Regression Analysis

Multiple regression analysis enables a study to assess the relationship between a dependent (predicted) variable and several independent (predictor) process indicators. The end result of a multiple regression analysis is the development of a regression equation (line of best fit) between the dependent and several independent process indicators. There are several types of multiple regression analyses available to a researcher such as standard, backward, forward, hierarchical and stepwise (Burns and Burns, 2008). Two regression procedures were employed in this study. The first is standard multiple regression analysis which determines the size of the overall relationship between the predicted variable and the independent (predictor) process indicators. Standard multiple regression analysis also details how much an independent (predictor) process indicator contributes to the relationship. The second regression procedure used in this study is stepwise multiple regression where the analysis produces the best combination of independent (predictor) process indicators to predict the dependent variable. Regression analysis is normally computed for interval and scale data. Overall total scores for each of the process indicator measurement scales were computed transforming the variables from ordinal data to metric scale data which allowed for multiple regression analyses.

Multiple regression analysis is extremely sensitive to outliers as outliers can produce regression equations (lines of best fit) closer to the outliers which changes the angle of the regression line (Burns and Burns, 2008). An inspection of the initial standard and stepwise multiple regression analyses produced outliers in the data. A deeper examination of these outliers determined that they were due to the non-applicable cases and respondents who answered in a different way to other science communicators in the online survey.

Outliers were not present in the initial regression analyses of the dependent variables of knowledge exchange, bridging ties and learning. The standard and stepwise multiple regression analyses were conducted again without the outlier cases for knowledge generation; knowledge transfer; network involvement; strong ties; trust; commitment; and reciprocity, as outliers affect the accuracy of prediction (Burns and Burns, 2008). The results of the regression analyses with the outliers and without the outliers were compared to assess variance levels and the significance of the independent (predictor) variables. The revised multiple regression analyses improved the variance of the regression equations and the data satisfied the assumptions of mutlicollinearity, normality of residuals and homoscedasticity (Burns and Burns, 2008). Therefore, the discussion within this section is limited to the standard and stepwise multiple regression analyses without outliers. Further information on the variance levels, anova results and significant regression coefficients of the multiple regression procedures with the outliers is presented in Appendix Eight.

5.4.1 Standard Multiple Regression Analysis

In standard multiple regression analysis, all predictor variables are entered into the regression equation at once. The remainder of this section interprets the results of each of the standard multiple regression analyses for the dependent variables of knowledge generation, transfer and exchange, network involvement, bridging and strong ties as well as trust, commitment, learning and reciprocity. A summary of the standard multiple regression printouts can be seen in Table 5.4.1.

Table 5.4.1 Standard Multiple Regression Analysis

Standard Multiple Regression Analysis				
Dependent Variable	**R**	**Adjusted R square**	**Anova**	**Significant Regression Coefficients**
Knowledge Generation	+0.706	.460	F value: 13.211; Sig: .000	K. Transfer (.000); N. Involvement (.023);
Knowledge Transfer	+0.854	.709	F value: 36.423; Sig: .000	K. Generation (.005); K. Exchange (.001); Strong Ties (.010); Trust (.000); Commitment (0.051)
Knowledge Exchange	+0.872	.742	F value: 43.275; Sig: .000	K. Transfer (.001); N. Involvement (.000); Strong Ties (.022); Trust (.001); Bridging Ties* (.058)
Network Involvement	+0.684	.428	F value:11.817; Sig: .000	K. Transfer (.037); K. Exchange (.000); Learning (.009); Reciprocity (.001)
Bridging Ties	+0.735	.506	F value: 16.048; Sig: .000	K. Generation (.042); Commitment (.003); Learning (.045); K. Exchange (.058)
Strong Ties	+0.849	.700	F value: 34.718; Sig: .000	K. Transfer (.014); K. Exchange (.003); Bridging Ties (.013); Trust (.019); Commitment (.002)
Trust	+0.833	.672	F value: 30.759; Sig: .000	K. Transfer (.000); K. Exchange (.001); Commitment (.025)
Commitment	+0.799	.639	F value: 24.003; Sig: .000	Bridging Ties (.000); Strong Ties (.003); Trust (.056); Learning (.037)
Learning	+0.585	.295	F value: 7.123; Sig: .000	Bridging Ties (.045); Commitment (.033)
Reciprocity	+0.575	.281	F value: 6.636; Sig: .000	N. Involvement (.000)

5.4.1.1 Knowledge Generation

A standard multiple regression analysis was conducted to evaluate how well the process indicators predicted the dependent variable of knowledge generation. The strong relationship between the variables was reflected in an R of +0.706 and adjusted R square of 0.460. The adjusted squared multiple correlation was significantly different from zero ($F = 13.211$, $p > .001$) and 46% of the variance in the dependent variable was explained by the set of independent knowledge, networking and relational process variables. The regression equation for predicting knowledge generation = 5.887 + 0.572 (knowledge transfer) + 0.249 (network involvement) + 0.275 (bridging ties).

5.4.1.2 Knowledge Transfer

A standard multiple regression analysis was conducted to evaluate how well the process indicators predicted the dependent variable of knowledge transfer. The strong relationship between the variables was reflected in an R of +0.854 and adjusted R square of 0.709. The adjusted squared multiple correlation was significantly different from zero ($F = 36.423$, $p > .001$) and 71% of the variance in the dependent variable was explained by the set of independent knowledge, networking and relational process variables. The regression equation for predicting knowledge transfer = 1.415 + 0.150 (knowledge generation) + 0.177 (knowledge exchange) + 0.193 (strong ties) + 0.380 (trust) + 0.098 (commitment).

5.4.1.3 Knowledge Exchange

A standard multiple regression analysis was conducted to evaluate how well the process indicators predicted the dependent variable of knowledge exchange. The strong relationship between the variables was reflected in an R of +0.872 and adjusted R square of 0.742. The adjusted squared multiple correlation was significantly different from zero ($F = 43.275$, $p > .001$) and 74% of the variance in the dependent variable was explained by the set of independent knowledge, networking and relational process variables. The regression equation for predicting knowledge exchange = 0.448 (knowledge transfer) + 0.556 (network involvement) + 0.289 (strong ties) + 0.557 (trust) + 0.384 (bridging ties) – 5.448.

5.4.1.4 Network Involvement

A standard multiple regression analysis was conducted to evaluate how well the process indicators predicted the dependent variable of network involvement. The strong relationship between the variables was reflected in an R of +0.684 and adjusted R square of 0.428. The adjusted squared multiple correlation was significantly different from zero ($F = 11.187$, $p > .001$) and 43% of the variance in the dependent variable was explained by the set of independent knowledge, networking and relational process variables. The regression equation for predicting network involvement = 4.269 + 0.337 (knowledge exchange) - 0.200 (knowledge transfer) - 0.172 (learning) + 0.202 (reciprocity).

5.4.1.5 Bridging Ties

A standard multiple regression analysis was conducted to evaluate how well the process indicators predicted the dependent variable of bridging ties. The strong relationship between the variables was reflected in an R of +0.735 and adjusted R square of 0.506. The adjusted squared multiple correlation was significantly different from zero ($F = 16.048$, $p > .001$) and 51% of the variance in the dependent variable was explained by the set of independent knowledge, networking and relational process variables. The regression equation for predicting bridging ties = 1.384 + 0.081 (knowledge generation) + 0.109 (commitment) + 0.085 (learning) + 0.076 (knowledge exchange).

5.4.1.6 Strong Ties

A standard multiple regression analysis was conducted to evaluate how well the process indicators predicted the dependent variable of strong ties. The strong relationship between the variables was reflected in an R of +0.849 and adjusted R square of 0.700. The adjusted squared multiple correlation was significantly different from zero ($F = 34.718$, $p > .001$) and 70% of the variance in the dependent variable was explained by the set of independent knowledge, networking and relational process variables. The regression equation for predicting strong ties = 0.796 + 0.199 (knowledge transfer) + 0.153 (knowledge exchange) + 0.292 (bridging ties) + 0.235 (trust) + 0.152 (commitment).

5.4.1.7 Trust

A standard multiple regression analysis was conducted to evaluate how well the process indicators predicted the dependent variable of trust. The strong relationship between the variables was reflected in an R of +0.833 and adjusted R square of 0.672. The adjusted squared multiple correlation was significantly different from zero ($F = 30.759$, $p > .001$) and 67% of the variance in the dependent variable was explained by the set of independent knowledge, networking and relational process variables. The regression equation for predicting trust = 0.255 (knowledge transfer) + 0.176 (knowledge exchange) + 0.093 (commitment) – 0.761.

5.4.1.8 Commitment

A standard multiple regression analysis was conducted to evaluate how well the process indicators predicted the dependent variable of commitment. The strong relationship between the variables was reflected in an R of +0.799 and adjusted R square of 0.639. The adjusted squared multiple correlation was significantly different from zero ($F = 24.003$, $p > .001$) and 64% of the variance in the dependent variable was explained by the set of independent knowledge, networking and relational process variables. The regression equation for predicting commitment = 3.841 + 0.771 (bridging ties) + 0.376 (strong ties) + 0.333 (trust) + 0.200 (learning).

5.4.1.9 Learning

A standard multiple regression analysis was conducted to evaluate how well the process indicators predicted the dependent variable of learning. The strong relationship between the variables was reflected in an R of +0.585 and adjusted R square of 0.295. The adjusted squared multiple correlation was significantly different from zero ($F = 7.123$, $p > .001$) and 30% of the variance in the dependent variable was explained by the set of independent knowledge, networking and relational process variables. The regression equation for predicting learning = 6.664 + 0.383 (bridging ties) + 0.168 (commitment).

5.4.1.10 Reciprocity

A standard multiple regression analysis was conducted to evaluate how well the process indicators predicted the dependent variable of reciprocity. The strong relationship between the variables was reflected in an R of +0.575 and adjusted R square of 0.281. The adjusted squared multiple correlation was significantly different from zero ($F = 6.636$, $p > .001$) and 28% of the variance in the dependent variable was explained by the set of independent knowledge, networking and relational process variables. The regression equation for predicting reciprocity = 9.651 + 0.522 (network involvement).

5.4.2 Stepwise Multiple Regression Analysis

In stepwise multiple regression analysis, not all independent (predictor) variables may end up in the equation. The remainder of this section interprets the results of each of the stepwise multiple regression analyses for the dependent variables of knowledge generation, transfer and exchange, network involvement, bridging and strong ties as well as trust, commitment, learning and reciprocity. A summary of the stepwise multiple regression printouts can be seen in Table 5.4.2.

Table 5.4.2 Stepwise Multiple Regression Analysis

Stepwise Regression Analysis without Outliers					
Dependent Variable	**Model No.**	**R**	**Adjusted R square**	**Anova**	**Significant Regression Coefficients**
Knowledge Generation	3	+0.741	.538	F value: 51.167; Sig: .000	K. Transfer (.000); N. Involvement (.000); Bridging Ties (.017)
Knowledge Transfer	5	+0.846	.705	F value: 63.686; Sig: .000	Trust (.000); K. Exchange (.000); Strong Ties (.002); K. Generation (.006); N. Involvement (.048)
Knowledge Exchange	5	+0.867	.741	F value: 76.686; Sig: .000	Trust (.000); N. Involvement (.000); K. Transfer (.000); Bridging Ties (.006); Strong Ties (.009)
Network Involvement	4	+0.660	.418	F value: 24.351; Sig: .000	K. Exchange (.000); Reciprocity (.000); Learning (.008); K. Transfer (.014)
Bridging Ties	3	+0.709	.491	F value: 43.490; Sig: .000	Commitment (.000); K. Exchange(.000); Learning (.029)
Strong Ties	6	+0.846	.701	F value: 51.824; Sig: .000	K. Exchange (.005); Commitment (.001); Trust (.023); N. Involvement (.052); Bridging Ties (.021); K. Transfer (.029)
Trust	3	+0.825	.673	F value: 90.735; Sig: .000	K. Exchange (.000); K. Transfer (.000); Commitment (.001)
Commitment	4	+0.792	.616	F value: 53.439; Sig: .000	Strong Ties (.000); Bridging Ties (.000); Trust (.001); Learning (.015)
Learning	2	+0.552	.294	F value: 28.474; Sig: .000	Commitment (.001); Bridging Ties (.003)
Reciprocity	2	+0.564	.307	F value: 29.827; Sig: .000	N. Involvement (.000); Learning (.021)

5.4.2.1 Knowledge Generation

A stepwise multiple regression was conducted to find the best combination of predictors of knowledge generation among the nine independent variables of knowledge, networking and relational processes. Only three steps were concluded with knowledge transfer, network involvement and bridging ties providing the best combination with adjusted R square of 54% and a significant F = 51.167, p = .001. Knowledge exchange, strong ties, trust, commitment, learning and reciprocity do not appear to be of any importance in determining knowledge generation. Thus, the stepwise regression equation for predicting knowledge generation = 4.857 + 0.629 (knowledge transfer) + 0.293 (network involvement) + 0.325 (bridging ties).

5.4.2.2 Knowledge Transfer

A stepwise multiple regression was conducted to find the best combination of predictors of knowledge transfer among the nine independent variables of knowledge, networking and relational processes. Five steps were concluded with trust, knowledge exchange, strong ties, knowledge generation and network involvement providing the best combination with adjusted R square of 71% and a significant F = 63.686, p = .001. Bridging ties, commitment, learning and reciprocity do not appear to be of any importance in determining knowledge transfer. Thus, the stepwise regression equation for predicting knowledge transfer = 2.459 + 0.413 (trust) + 0.187 (knowledge exchange) + 0.226 (strong ties) + 0.145 (knowledge generation) – 0.131 (network involvement).

5.4.2.3 Knowledge Exchange

A stepwise multiple regression was conducted to find the best combination of predictors of knowledge exchange among the nine independent variables of knowledge, networking and relational processes. Five steps were concluded with trust, network involvement, knowledge transfer, bridging ties and strong ties providing the best combination with adjusted R square of 74% and a significant F = 76.686, p = .001. Commitment, learning, reciprocity and knowledge generation do not appear to be of any importance in determining knowledge exchange. Thus, the stepwise regression equation for predicting knowledge exchange = 0.598 (Trust) + 0.612 (network involvement) + 0.498 (knowledge transfer) + 0.508 (bridging ties) + 0.316 (strong ties) – 3.547.

5.4.2.4 Network Involvement

A stepwise multiple regression was conducted to find the best combination of predictors of network involvement among the nine independent variables of knowledge, networking and relational processes. Four steps were concluded with knowledge exchange, reciprocity, learning and knowledge transfer providing the best combination with adjusted R square of 42% and a significant F = 24.351, p = .001. Knowledge generation, bridging ties, strong ties, trust and commitment do not appear to be of any importance in determining network involvement. Thus, the stepwise regression equation for predicting network involvement = 5.619 + 0.322 (knowledge exchange) + 0.217 (reciprocity) - 0.165 (learning) - 0.198 (knowledge transfer).

5.4.2.5 Bridging Ties

A stepwise multiple regression was conducted to find the best combination of predictors of bridging ties among the nine independent variables of knowledge, networking and relational processes. Only three steps were concluded with commitment, knowledge exchange and learning providing the best combination with adjusted R square of 49% and a significant F = 43.490, p = .001. Strong ties, trust, reciprocity, knowledge generation, knowledge transfer and network involvement do not appear to be of any importance in determining bridging ties. Thus, the stepwise regression equation for predicting bridging ties = 1.636 + 0.132 (commitment) + 0.106 (knowledge exchange) + 0.091 (learning).

5.4.2.6 Strong Ties

A stepwise multiple regression was conducted to find the best combination of predictors of strong ties among the nine independent variables of knowledge, networking and relational processes. Six steps were concluded with knowledge exchange, commitment, trust, network involvement, bridging ties and knowledge transfer providing the best combination with adjusted R square of 70% and a significant F = 51.824, p = .001. Knowledge generation, learning and reciprocity do not appear to be of any importance in determining strong ties. Thus, the stepwise regression equation for predicting strong ties = 0.095 + 0.143 (knowledge exchange)

+ 0.154 (commitment) + 0.227 (trust) - 0.122 (network involvement) + 0.260 (bridging ties) + 0.164 (knowledge transfer).

5.4.2.7 Trust

A stepwise multiple regression was conducted to find the best combination of predictors of trust among the nine independent variables of knowledge, networking and relational processes. Only three steps were concluded with knowledge exchange, knowledge transfer and commitment providing the best combination with adjusted R square of 67% and a significant F = 90.735, p = .001. Knowledge generation, network involvement, bridging ties, strong ties, learning and reciprocity do not appear to be of any importance in determining trust. Thus, the stepwise regression equation for predicting trust = 0.165 (knowledge exchange) + 0.261 (knowledge transfer) + 0.116 (commitment) **–** 1.473.

5.4.2.8 Commitment

A stepwise multiple regression was conducted to find the best combination of predictors of commitment among the nine independent variables of knowledge, networking and relational processes. Four steps were concluded with strong ties, bridging ties, trust and learning providing the best combination with adjusted R square of 62% and a significant F = 53.439, p = .001. Knowledge generation, knowledge transfer, knowledge exchange, network involvement and reciprocity do not appear to be of any importance in determining commitment. Thus, the stepwise regression equation for predicting commitment = 3.853 + 0.450 (strong ties) + 0.778 (bridging ties) + 0.486 (trust) + 0.227 (learning).

5.4.2.9 Learning

A stepwise multiple regression was conducted to find the best combination of predictors of learning among the nine independent variables of knowledge, networking and relational processes. Only two steps were concluded with commitment and bridging ties providing the best combination with adjusted R square of 29% and a significant F = 28.474, p = .001. Reciprocity, knowledge generation, knowledge transfer, knowledge exchange, network involvement, strong ties and trust do not appear to be of any importance in determining learning. Thus, the stepwise regression equation for learning = 6.626 + 0.226 (commitment) + 0.505 (bridging ties).

5.4.2.10 Reciprocity

A stepwise multiple regression was conducted to find the best combination of predictors of reciprocity among the nine independent variables of knowledge, networking and relational processes. Only two steps were concluded with network involvement and learning providing the best combination with adjusted R square of 31% and a significant F = 29.827, p = .001. Knowledge generation, knowledge transfer, knowledge exchange, bridging ties, strong ties, trust and commitment do not appear to be of any importance in determining reciprocity. Thus, the stepwise regression equation for reciprocity = 2.672 + 0.603 (network involvement) + 0.167 (learning).

5.4.3 Discussion

The main finding from multiple regression is that there is an interlinked and interconnected relationship between the knowledge, networking and intangible process indicators of this study. The stepwise multiple regression analysis produced findings consistent with the literatures of science communication, social marketing and innovation theory. Knowledge generation is best predicted by knowledge transfer, network involvement and bridging ties. The generation of knowledge in regression analysis seeks explicit knowledge (Katsamakas, 2007) though bridging ties where the information is transferred between STEM co-workers. Knowledge which is external to an organisation such as specialised tacit knowledge (Katsamakas, 2007) is gathered through network involvement where STEM communicators interact and communicate with one another.

Knowledge transfer concerns a logical one-way flow of information (Jacobson, 2007) where the process is predicted by trust, strong ties, knowledge exchange and generation and network involvement. Social marketing and innovation theory suggest that knowledge transfer is a unilateral process where Buchanan, Reddy and Hossain (1994) identify the process to be subsumed with self-interest. However, trust was identified as a predictor of knowledge transfer, suggesting that the process of moving knowledge requires mutual benefits and non-malicious behaviour (Hunt and Morgan, 1994).

Knowledge exchange in the literature means interactivity and a propensity to act on both sides (Prahalad and Ramaswamy, 2004) and is supported by the findings of stepwise multiple regression as trust, knowledge transfer, network involvement and strong and bridging ties were recognised as predictors of knowledge exchange.

Strong ties in comparison to bridging ties produced more predictor variables. This co-aligns with the supporting literature on network ties as respondents become committed to their long-term connections and relationships with colleagues in the STEM industry.

In relation to trust and commitment, the findings supported the thinking of Hunt and Morgan (1994) as both trust and commitment are viewed as antecedents to the formation of relationships. Trust, as previously alluded to becomes central to the transfer and exchange of knowledge, whereas commitment and sequential forms of interaction (Kramer and Wells, 2005) are important for strong and bridging ties. Commitment is also linked to learning; the outcome of relational processes (Hunt and Morgan, 1994).

Network involvement and reciprocity are interlinked predictors in stepwise regression. Those who network have an expectation of reciprocity, where there is mutual exchange of information and/or resources in science communication supporting the writing of Parung and Bititci (2006) in innovation. This finding conflicts with the literature of Hamel, Doz and Prahalad (1989) and Walker, Kogut and Shan (1997) who argue that involvement embodies a competitive or exploitative element in network formation.

The findings from multiple regression analysis reflect the science communication, social marketing and innovation literatures and conflict with the theoretical insights of Hamel, Doz and Prahalad (1989), Buchanan, Reddy and Hossain (1994) and Walker, Kogut and Shan (1997). The next section provides a thematic analysis of the final question on the National STEM Survey.

5.5 Thematic Analysis of Open-Ended Question

The final question on the online survey asked '***from your personal perspective, how would you like to see the area of STEM progress?***' This question was optional to respondents and yielded a response rate of 74.8%, as ninety-eight respondents took the time to express their opinion on the future of STEM. The character count in the question was unlimited to allow respondents to provide comprehensive and unrestricted opinions.

The ninety-eight responses were pattern matched by the researcher and organised into six dominant themes, as illustrated in Table 5.5.

Table 5.5 Thematic Analysis

Themes	Thematic Areas	Subset of Thematic Areas
Theme 1: Emotional Orientation	Public Appreciation Recognition	
Theme 2: Structural Orientation	Governance* → Funding Growth Employment	Corporate Governance National Governance Policy Makers
Theme 3: Integrated Orientation	Networks Engagement Linkages between academia and industry Sharing Communication and Cooperation Databases and Forums Media	
Theme 4: Professional Development Orientation	Education* → Training Research	Primary Level Education; Second Level Education; Third Level Education
Theme 5: Cultural Orientation	Outreach	
Theme 6: Barriers	Issues with STEM	

Five of the themes revolve around specific orientations of the respondents (emotional; structural; integrated; professional development; and cultural). The last theme which yielded two responses concerns the barriers of STEM.

5.5.1 Theme One: Emotional Orientation

Theme one represents the emotional orientation of STEM, where respondents were mainly concerned about public appreciation and recognition. In terms of public appreciation, respondents hoped that there would be "*better public awareness of STEM*" and a "*greater societal understanding of STEM*". Respondents felt that the public were not aware of the importance of STEM in their everyday lives. This was especially evident in the response of one science communicator who explained the following:-

> "*I would like to see a better understanding of the fact that STEM underpins, and will continue to underpin even more so in the future, our daily lives. There was a time when the STEM disciplines were sort of set apart from real life in that they were disciplines to be studied but the link wasn't made as to how they would form the basis of what we do in our daily lives. Just look at the functions of smart phones, the disciplines involved in their development and what they enable us to do. STEM will only increase in importance in the future*".

Science communicators want to create a seamless understanding and linkage between science-for-science and science-for-society where science outreach, promotion and communication can raise "*the profile and esteem of STEM among the wider public*". One respondent felt that the profile of STEM was not accessible to the public because of its image as an academic subject. Instead, public appreciation according to this science communicator results from the:-

> "*Continued awareness of STEM accepted as being a part of all our lives and not purely curricular, academic or industry related. A greater fusion of STEM with STEAM to bring art and culture closer as associate curiosity/innovator drivers/expressions. Making STEM cultural*."

The emotional orientation is also influenced by recognition, where science communicators want to see "*more publicity of achievements*". Science communicators feel that often times their hard work and dedication to STEM goes unnoticed, especially outside the confinements of their respective organisations and institutions. Science communicators want to see more "*credit to people working in the area*" as they feel STEM workers are "*taken for granted*" and that "*people are not recognised for their contributions*".

5.5.2 Theme Two: Structural Orientation

The structural orientation of science communication concerns its governance, funding, growth and employment. In relation to governance at the corporate and national levels, science communicators feel there is an evident divide between the policy level of science and the practice level where "*everyone seems to be involved doing separate work*". Science communicators would prefer to see "*a more joined, unified approach which would be more powerful*" for STEM. Furthermore, science communicators would like policy makers to be more visible as respondents felt that "*interactions with policy make it key*".

Funding emerged as a significant issue for many science communicators. The need for additional funds is reflective of the recessionary times we live in, given the cuts to science, technology and education. Science communicators want to secure further public funding with "*less administration/bureaucracy*". In addition to the procurement of additional funds, science communicators also called for "*incentive systems*" and "*better targeted funding to strategically build and sustain resources in identified strength areas*".

Science communicators want to see STEM grow "*organically*" and to see "*far greater orientation towards (scientific, engineering, mathematics, etc.) disciplines rather than being purely process oriented*". The area of STEM, like its governance, incorporates many separate and distinct activities. Science communicators would like to see a "*nationally coordinated approach towards STEM*" where all stakeholders collaborate and coordinate resources with one another, producing "*more cohesion*" in science communication.

In terms of employment, a respondent wanted to see "*more employment opportunities for those that engage in STEM, particularly the sciences*".

5.5.3 Theme Three: Integrated Orientation

Theme three of the integrated orientation resulted in the thematic areas of networks, engagement, linkages between academia and industry, sharing, communication and cooperation, databases and forums, and media. In terms of networking and engagement, science communicators would like a "*more cohesive and transparent network of people/organisations with a common goa*l" where it is "*easier to make connections between partners*". Science communicators attributed the integrated orientation of networking with other science communicators and organisations, while engagement was predominantly associated with the public as science communicators wanted to see "*more public engagement*".

One science communicator wanted "*more engagement from the department of education and industry at local level, more integration into the arts; other areas to draw new audiences; and create new links that are there, but not obvious*". The linkage with industry emanated in the responses of other science communicators who wanted to see "*more real and direct interaction between industry and academia*".

Communication and the sharing of resources proved a contentious, yet important facet of science communication. There was agreement between science communicators that better communication is needed in STEM. One science communicator was especially vocal in this regard:-

> "*Better communication - not websites or brochures but interpersonal communication. Websites are an abdication of teaching responsibilities and resources to computer based methods. We are not robots, most learning is done through experience -talking and listening to people and*

> *practicing same (experiments etc.) - not through producing endless reams of data on a website. Teaching methods and teachers (at all levels) need to improve*".

Science communicators want to see an affective change in the communication styles of many audiences in STEM as respondents want "*better communication of STEM to the general public and a better understanding by policy makers of the importance of STEM*". Science communicators feel that the provision of resources for STEM activities is inadequate and would like to see the development of a comprehensive database or online forum in STEM. Science communicators are also interested in the formation of meaningful relationships with the media for "*shared knowledge, wisdom and the transfer of information*" which allows STEM to be "*more widely discussed in the media*".

5.5.4 Theme Four: Professional Development Orientation

Professional development is a particularly important area in STEM as it incorporates education, research and training. STEM education occurs at three levels; primary level, secondary level and third level. One respondent was particularly vocal regarding the importance of science in education as the science communicator would "*like to see science replace religion as the fundamental basis of our education system*". Science communicators want to see more participation in science subjects and would "*like to see STEM be more engaging for young people so that they are interested, enthused and motivated*" and become "*lifelong learners with excellent STEM skills/knowledge*".

In addition to students of STEM and the pursuit of careers in STEM, science communicators want:-

> "*More continuous professional development for teachers and educators and a more dynamic approach to updating and adapting content taught in schools to facilitate a wider awareness of current STEM. Better and more effective teaching of maths at all levels*".

Research contracts in STEM were viewed by one participant as a major area of concern as they induce disillusionment among scientific researchers employed in the public sector, given researchers "*pay a pension levy for a pension that they don't even receive as they are on contract*".

5.5.5 Theme Five: Cultural Orientation

The cultural orientation of STEM relates to outreach as science communicators would like "*to see a focus on embedding STEM within the culture of the country*". Frequently, science outreach is integrated with science education as is the case in the response of one science communicator who voiced:-

> "*For STEM to succeed in developing a critical, creative, innovative, entrepreneurial, socially aware and dynamic population to usher in a Knowledge-based society, we need: a) an emphasis on project-based learning in second-level schools b) the introduction of computer programming into the second-level curriculum c) the introduction of IT technicians (shared between smaller schools) to allow teachers to teach and not to spend classes fixing broken computers e) the introduction of formal community and school outreach modules to all third level courses, whereby students are encouraged to spread their relevant course expertise to schools and to communities f) encouraging private companies management to promote relevant and meaningful Outreach activities for their staff that can benefit society*".

Science communicators assert that outreach in STEM "*challenges students to think*" and also "*builds trust with communities and breaks down awareness barriers. This has the potential to develop a new generation unafraid to explore the exciting world of STEM*". Science communicators maintain that greater public awareness and appreciation of science can create a better informed society, producing a positive outlook and view on STEM in the future.

5.5.6 Barriers

One respondent wrote an impassioned critique of the STEM acronym, whilst also vocalising the culture of their respective organisation, as illustrated below:-

> "*I don't see the STEM designation as useful. These areas are not separate from other areas of teaching and research. This designation is unhelpful, likely to lead to establishment of goals that embed disciplinary isolation, while affirming existing self-referencing targets. There are bigger issues. In my answers, I'm struggling to identify the extreme difference between the functioning collegiality among practitioners, versus the dysfunctional authoritarianism of managers, in our organisation. There are further issues with government, and among the universities, but this level is where the rot is now … with a serious problem in corporate governance*".

This science communicator views science as a hierarchical process of segregation where managers and practitioners have very clear and divisive roles in their respective organisation. Furthermore, this respondent views the acronym as STEM as unhelpful, as it creates a clear and isolated divide between science and other areas of teaching and research.

5.5.7 Discussion

The main finding from the thematic analysis is that science communication at present, embraces a closed hierarchical system of governance and the future of STEM requires openness, integration and equal participation between the policy, practice and public levels of science communication. The future of STEM corresponds to the participative thinking in the science communication literature. Active science communicators from industry are calling for "*more openness and sharing of best practice*" which supports the writing of Stirling (2006; 2008), Chilvers (2008; 2009) and Lengwiler (2008). This apt quote also reflects the appropriateness of integrating science communication with social marketing and innovation theory as total market approaches (Lefebvre, 2011) and open co-innovation processes (Lee, Olson and Trimi, 2012) embody openness and the sharing of best practices within and across the levels of science communication.

5.6 Chapter Summary

The data presented in the correspondence analysis identified that the nominal variable of STEM roles is significantly associated with STEM areas and Target audiences. Following correspondence analysis, EFA was employed to identify the underlying factor structures of the process indicators. EFA succeeded in identifying the underlying factor structures, producing six unidimensional constructs and four multidimensional constructs. The multidimensional constructs produced a further eight factors consisting of human capital, system capital, interactive communication, internal interaction, loyalty, organisational involvement, promotive interactive and group processes. Standard and stepwise multiple regression analyses were also performed to interpret the relationships between the dependent (predicted) variables and the independent process indicators. The results from regression analysis were connected with the theoretical conceptualisations of science communication, social marketing and innovation. To conclude the chapter, a thematic analysis of the future of STEM was outlined and the findings were contrasted against the theory in science communication.

The process indicators examined in this chapter are analysed further in the final sequential phase of this research. The findings from this final qualitative phase are presented in the next chapter.

Chapter Six: Value Network Findings and Analysis

6.0 Introduction

This chapter presents the findings from the second phase of this sequential explanatory study. More specifically, the purpose of this chapter is to present the qualitative findings that answered the primary research question of this study; '*how do process indicators contribute to the understanding of activities betweens science communicators in Ireland*' and the secondary research objective of '*how value is created between science communicators*'. VNA in this study was used to determine the networking activities of science communicators. VNA goes beyond 'who' is involved in a network and effectively captures 'what' is exchanged and 'how' those exchanges take place in science communication.

This chapter begins with a reductionistic discussion on the participant profiles from the semi-structured interviews. A reductionistic analysis in VNA provides in-depth information on the system contributors to science as well as the exchanges that take place between networking organisations in STEM. Reductionism in VNA begins with the illustration and examination of the value networks maps of each of the participants. The roles of each participant and their respective networking partners are identified as well as the key transactions and deliverables within each network. Following reductionism, a collective and holistic analysis of science communication as a system is presented through an exchange analysis and an impact analysis. Holistic VNA amalgamates the findings from each of the value network maps and assesses science communication as a system where the "whole is greater than the sum of the parts" (Langlois, 1983, p.583). The remainder of the chapter links the findings from the sequential phase of this qualitative research to the literature on the four process indicator categories. The chapter begins with an outline of the profile of the interviewees.

6.1 Participant Profiles

A total of seven science communicators participated in the value network mapping exercise. In relation to the profile of these respondents, four of the interviewees primarily work in science education, two interviewees influence science policy and the remaining interviewee emphasises science outreach with the public.

In the semi-structured interviews, respondents illustrated that the roles of science communicators are not mutually exclusive as shown in Table 6.1. In fact, science communicators serve a plurality of roles as they influence, support and contribute to science education, science outreach, science policy and the education curriculum, simultaneously.

Table 6.1 Roles and Experience

Participant	Primary Role	Additional Roles and Experience in STEM
A	**Science Education**	Facilitates outreach at the community level with parents, the elderly and the unemployed; Mediates with authority groups on cyber-bullying and internet security.
B	**Science Education**	Influences education at national and international levels; Influences national and international science education curriculums; Engages with the public in science outreach; Connects STEM organisations and key people.
C	**Science Education**	Creates links between academia and industry; Shares best practices with other outreach officers.
D	**Science Policy**	Visits schools; Delivers public lectures on climate change and environmental issues; Trains local authority groups on regulative procedures.
E	**Science Outreach**	Connects with educational institutions at primary, secondary and tertiary levels; Shares best practices with other outreach organisations; Assists local heritage and cultural groups.
F	**Science Education**	Connects with commercial organisations in industry; Protects research with IP's.
G	**Science Policy**	Influences science policy and the education curriculum; Engages with industry experts; Promotes engineering excellence with profiles; Connects with educators and the general public.

For instance, Participant A primarily works in science education, but also facilitates science outreach at the community level with parents, the elderly and the unemployed. Participant B works specifically in science education but at national and international levels, whilst also influencing national and international science education curriculums and engaging with the public in science outreach activities. Participant C works in education as an outreach officer and creates links between academia and industry. Participant D influences science policy and regulation, whilst also visiting schools and delivering public lectures on climate change and environmental issues. Participant E works predominantly in science outreach and could not operate without the general public, yet the organisation also connects with educational institutions at primary, secondary and tertiary levels. Participant F works predominantly in science education, but like Participant C, connects with commercial organisations in industry. And finally, Participant G operates at all levels of science; influencing science policy and the education curriculum, whilst also engaging with industry experts, educators and the general public.

In consequence to the pluralistic roles of science communicators, these organisations also serve multi-faceted target audiences which span from government and state agencies to teachers, students and public society. This profile breakdown alone supports the iterative and participative nature to the three levels of science communication, as policy, practice and public levels interact *with*, *through* and *across* one another, facilitating science communication.

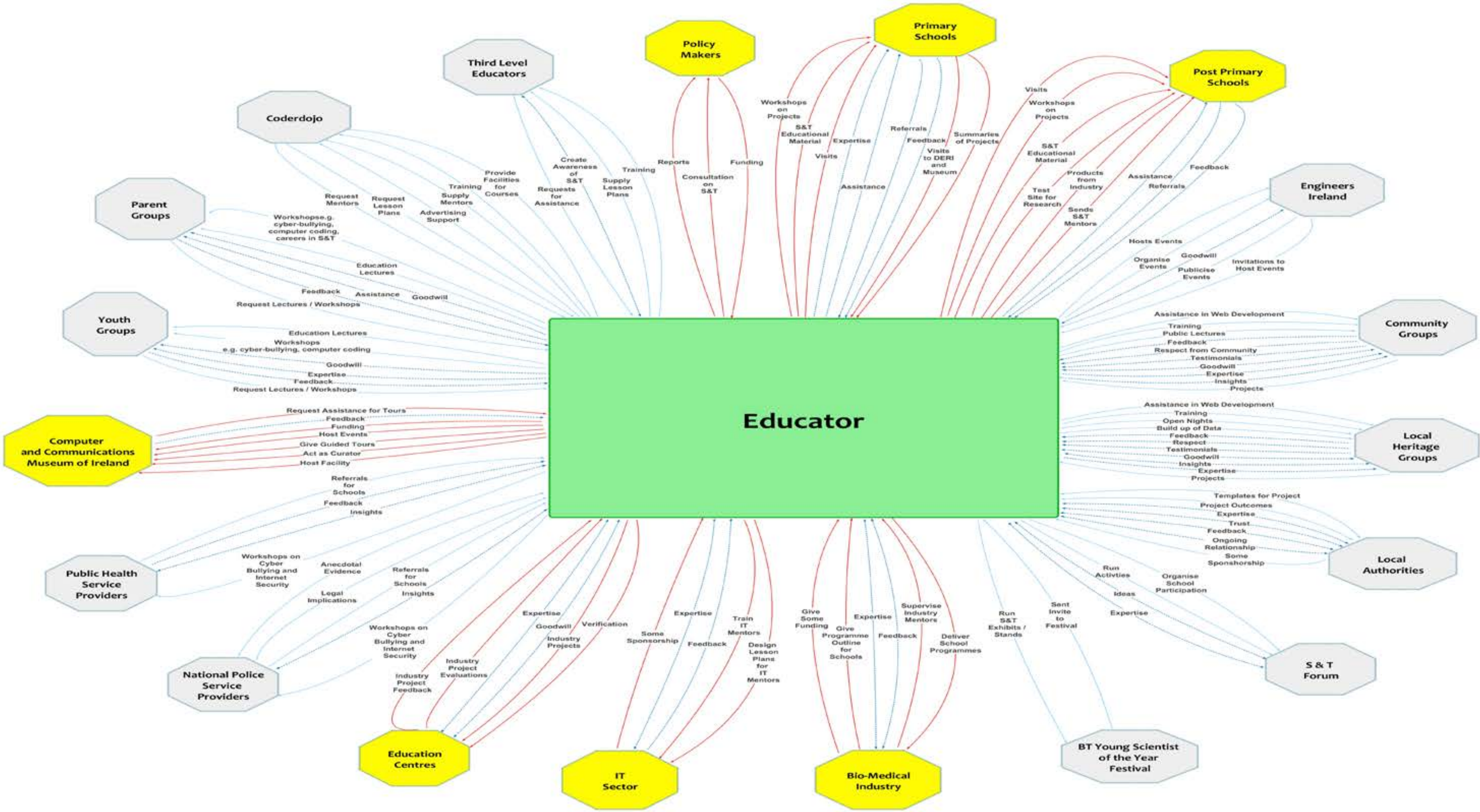
6.2 Value Network Maps

The first element of the semi-structured interviews involved the design of the value network map. A value network map consists of "specific roles and value interactions oriented toward the achievement of a particular task or outcome. The active agents of the network are real people who participate in the network by playing particular roles in which they convert both tangible and intangible assets into negotiable offerings and fulfil different functions" (Allee, 2008, p.6). This section presents the value network maps of each of the participants and discusses the deliverables from each map.

6.2.1 Participant A

Participant A works in science education in a third level institution. Participant A identified their role as an 'Educator' as can be seen in Figure 6.2.1.

Figure 6.2.1 Value Network Map of Participant A



For the purposes of this research, the value network maps can also be found in appendices nine to fifteen to facilitate the in-depth examination of the transactions, and the direction and labelling of the deliverables which may not be clearly outlined in the value network maps. Participant A chose ‘educator’ as their role as the interviewee is based in a third level institution, but also lectures students and teachers at primary and secondary levels. In addition to mainstream education, Participant A also educates societal groups in terms of technology, internet security and cyber bullying.

The educator identified nineteen networking groups, seven of which are contractual and identified by the yellow nodes, and twelve of which are non-contractual and are identifiable by the grey coloured nodes in the value network map. Furthermore, the educator identified that non-contractual connections emanated from their relationships with contractual groups in the network, producing an informal snowball effect to the coordination of new networks.

In VNA, Allee (2008) suggests that organisations are discrete entities which consist of real people playing a variety of roles in different activities. The identification of value networks takes two forms; role-based and participant-based. The context of labelling networks in this study differs from its traditional application, as value network maps cluster multiple societal and industry groups together, as opposed to traditional networks which emphasise individual entities and stakeholders. Consequently, generic participant-based labels are allocated to the networking groups. The educator in this map decided to name specific networking groups such as the Computer and Communications Museum of Ireland, Coderdojo and Engineers Ireland, whilst also giving generic labels to networks such as Parent Groups, Policy Makers, Local Authorities and Local Heritage Groups. This particular method worked best for the study as science communicators and organisations serve a plurality of roles, as previously outlined, where the assignment of role-based labels to each network was found to be both unfeasible and impractical. As was determined in the pre-test, participants felt more comfortable assigning themselves a role and assigning their networking groups both generic and specific participant-based labels.

The value network map of this educator exhibits many transactions or activities which begin with one network group and end with another network group. The solid red lines represent formal contract exchanges; the solid dark blue lines represent explicit flows of resources and knowledge; and the dashed light blue lines depict implicit and intangible flows of science communication expertise and benefits.

The totality of intangible deliverables is more evident in the work of the educator than are tangible deliverables, as it evidenced in Tables 6.2.1. Impact analyses figures represent the inward flow of tangible and intangible deliverables from networks to the educator, while value creation figures represent the outward flow of deliverables from the educator to its networks. It is evident that the educator provides more deliverables to its networking partners than it receives back. Separate maps of the impact and value creation analysis are provided in Appendix Nine. The reciprocal exchange of deliverables is synonymous with intangible relationships in this map, as twenty identical exchanges take place between the educator and their networking partners. This reciprocity is represented by a double arrowed line in the network map.

Table 6.2.1 Tangible and Intangible Deliverables of Participant A

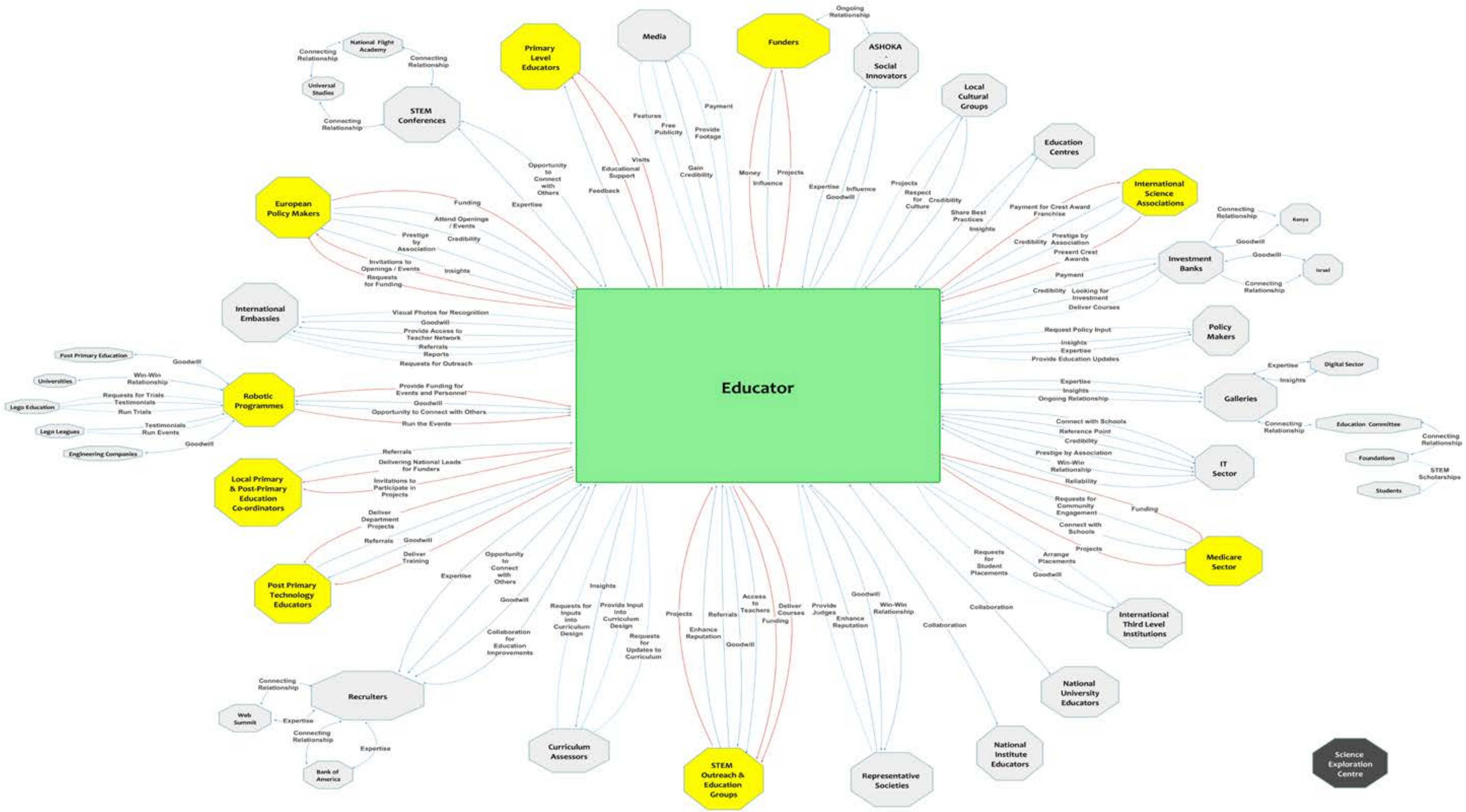
Participant	TANGIBLE DELIVERABLES			
	All	Impact Analysis	Value Creation	Both Impact and Value
A-Educator	31	10	21	-

Participant	INTANGIBLE DELIVERABLES						
	All	Impact Analysis		Value Creation		Both Impact and Value	
		Explicit	Implicit	Explicit	Implicit	Explicit	Implicit
A-Educator	84	15	15	24	10	2	18

6.2.2 Participant B

Participant B works in a science education centre and again identified themselves as an ‘educator’. The value network map of Participant B is illustrated in Figure 6.2.2.

Figure 6.2.2.0 Value Network Map of Participant B



Participant B created a large network map as the educator perceived themselves as a "*connector*" in their network. The educator has twenty-six direct networks, of which nine (yellow) networks are contractual, sixteen (grey) networks are non-contractual and one (black) network is dormant. Unlike Participant A, this educator has a further fifteen connecting networks, four of which stem from non-contractual relationships and one which emanated from a contractual network.

The educator connects with multi-faceted groups at both national and international levels, as reflected in the networks with overseas Embassies, Third Level Institutions, Investment Banks and International Lego Leagues. The educator is also involved in science education, curriculum assessment, curriculum improvements and science outreach activities with the public and various other community groups.

Table 6.2.2 represents the tangible and intangible deliverables of the educator. The exchange of intangible deliverables outweighs tangibles deliverables (73 > 21). Furthermore, there is a marginal difference between impact network deliverables (8 + 7 + 15 = 30) and value creation deliverables (12 + 8 + 18 = 38), purporting a balanced relationship between the educator and the networking groups. The facilitation of reciprocal exchange is evident, as twenty-six impact and value deliverables are simultaneously exchanged between the educator and networking groups.

Table 6.2.2 Tangible and Intangible Deliverables of Participant B

Participant	TANGIBLE DELIVERABLES			
	All	**Impact Analysis**	**Value Creation**	**Both Impact and Value**
B-Educator	21	8	12	1

Participant	INTANGIBLE DELIVERABLES						
	All	**Impact Analysis**		**Value Creation**		**Both Impact and Value**	
		Explicit	**Implicit**	**Explicit**	**Implicit**	**Explicit**	**Implicit**
B-Educator	73	7	15	8	18	2	23

The educator maintains that apart from its funding network; the majority of networks are formed through conversations. The educator deemed this type of network formation to result from "*conversation crossover networking*" where individuals and organisations just talk to one another. An example of a conversational network is illustrated in Figure 6.2.2.1. This conversational network began at a STEM conference in Ireland with an informal conversation between the educator, a teacher and the director of Universal Studios from the United States. This conversational network progressed into a powerful relationship where Irish students got the chance to represent Ireland in the Aviator of the Future Competition, an idea borne out of the conversations in this network. These informal conversational ideas have now developed and transformed into a long term relationship with mutual benefits, connectivity and reciprocity between Universal Studios, the International Flight Academy (renamed as a consequence of this network), the teacher and the educator.

Figure 6.2.2.1 Conversational Network

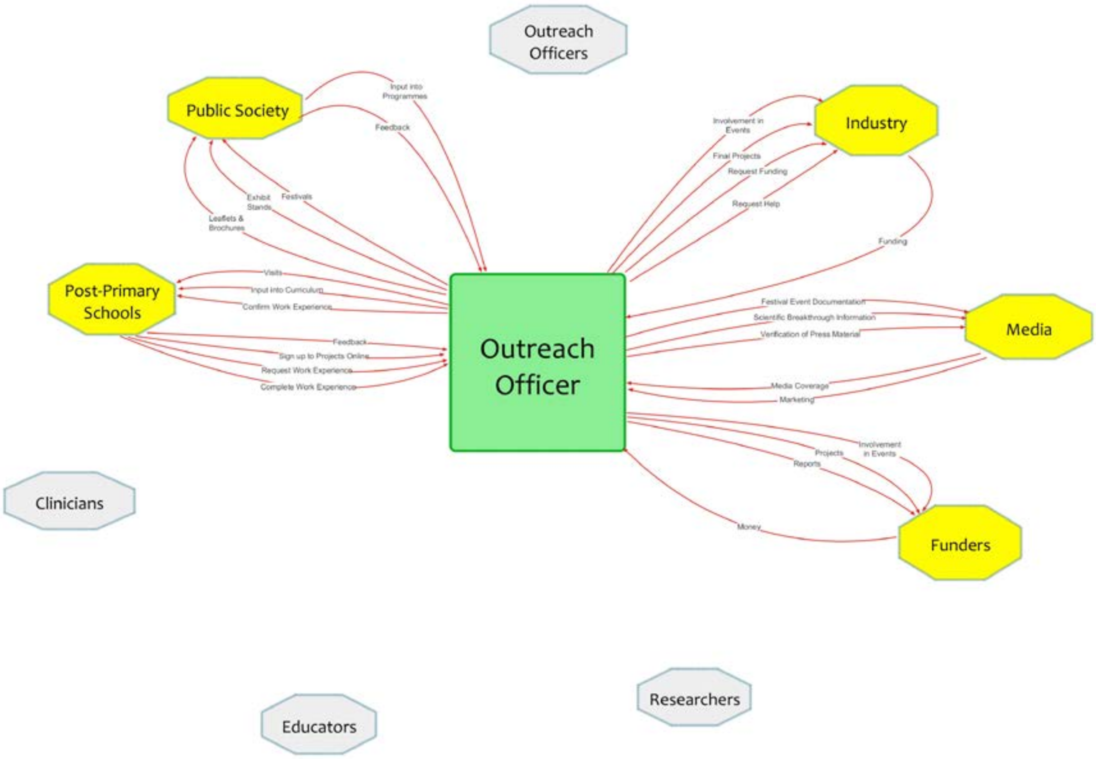
6.2.3 Participant C

Participant C identified themselves as an outreach officer. An outreach officer in science communication is normally associated with the public but in this instance, the outreach work of Participant C involves the "*public and debating science issues, strengthening education links, working in public and patient outreach programmes and being actively involved in Eurostemcell which is Europe's stem cell hub*".

The outreach officer has a small network portfolio consisting of nine network groups. The outreach officer has five contractual networks and four non-contractual networks, creating a balance between formal and informal network associations. The tangible deliverables of the outreach officer can be seen in Figure 6.2.3.0 where there are more outgoing value creating deliverables than inward impact deliverables.

Figure 6.2.3.0 Tangible Deliverables of Participant C

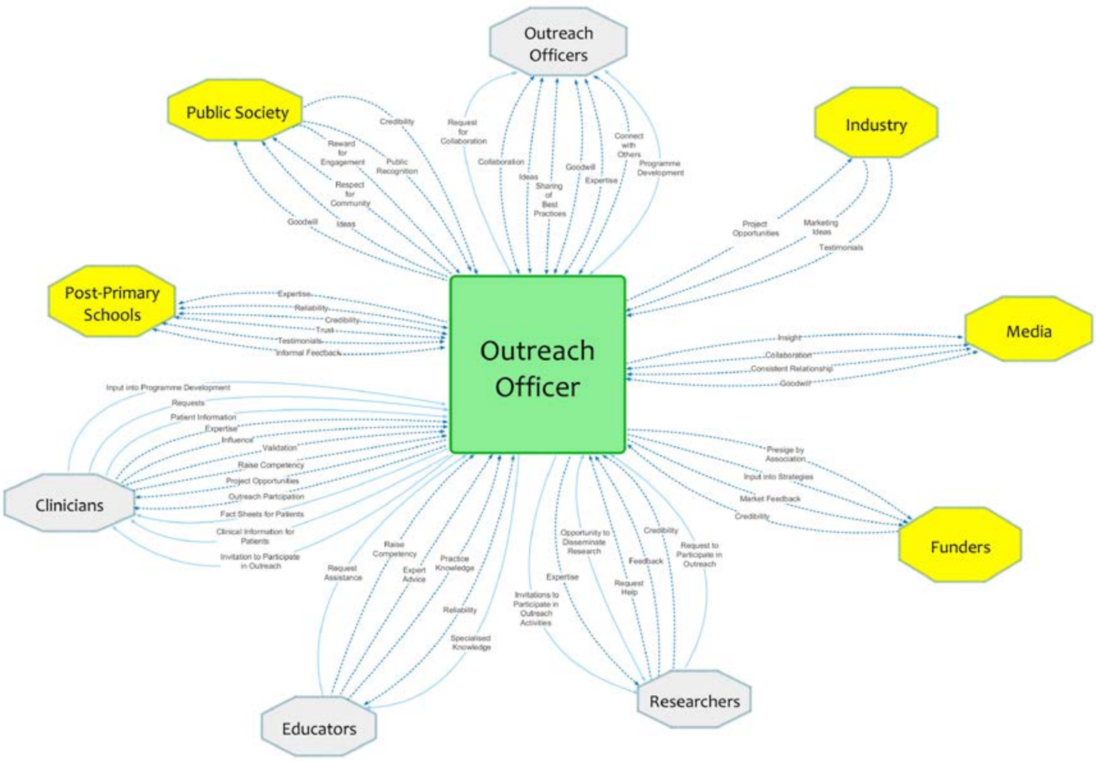
Participant	TANGIBLE DELIVERABLES			
	All	**Impact Analysis**	**Value Creation**	**Both Impact and Value**
C – Outreach Officer	26	10	16	-



The work of the outreach officer, like the previous educators, highlights the importance of intangible relationships and the exchange of explicit and implicit intangibles as is seen in Figure 6.2.3.1. In terms of the explicit intangibles, the outreach officer is involved in a lot of requests for collaboration, information and data pertaining to programme developments and patient groups. This explicit information is contained in formal documents and systems. Alternatively, implicit intangibles include human capital knowledge like expertise and insights. Relational intangibles such as trust, goodwill, credibility and reliability are also exchanged between the outreach officer and the networks, reflecting dimensions of the trust and commitment process indicators.

Figure 6.2.3.1 Intangible Deliverables of Participant C

Participant	INTANGIBLE DELIVERABLES						
	All	Impact Analysis		Value Creation		Both Impact and Value	
		Explicit	Implicit	Explicit	Implicit	Explicit	Implicit
C-Outreach Officer	56	5	16	5	11	3	16



Reciprocity is evident in the network exchanges of the outreach officer, particularly in the case of implicit intangibles. Reciprocal exchanges occur mainly with outreach officers, the media and post-primary schools for Participant C.

6.2.4 Participant D

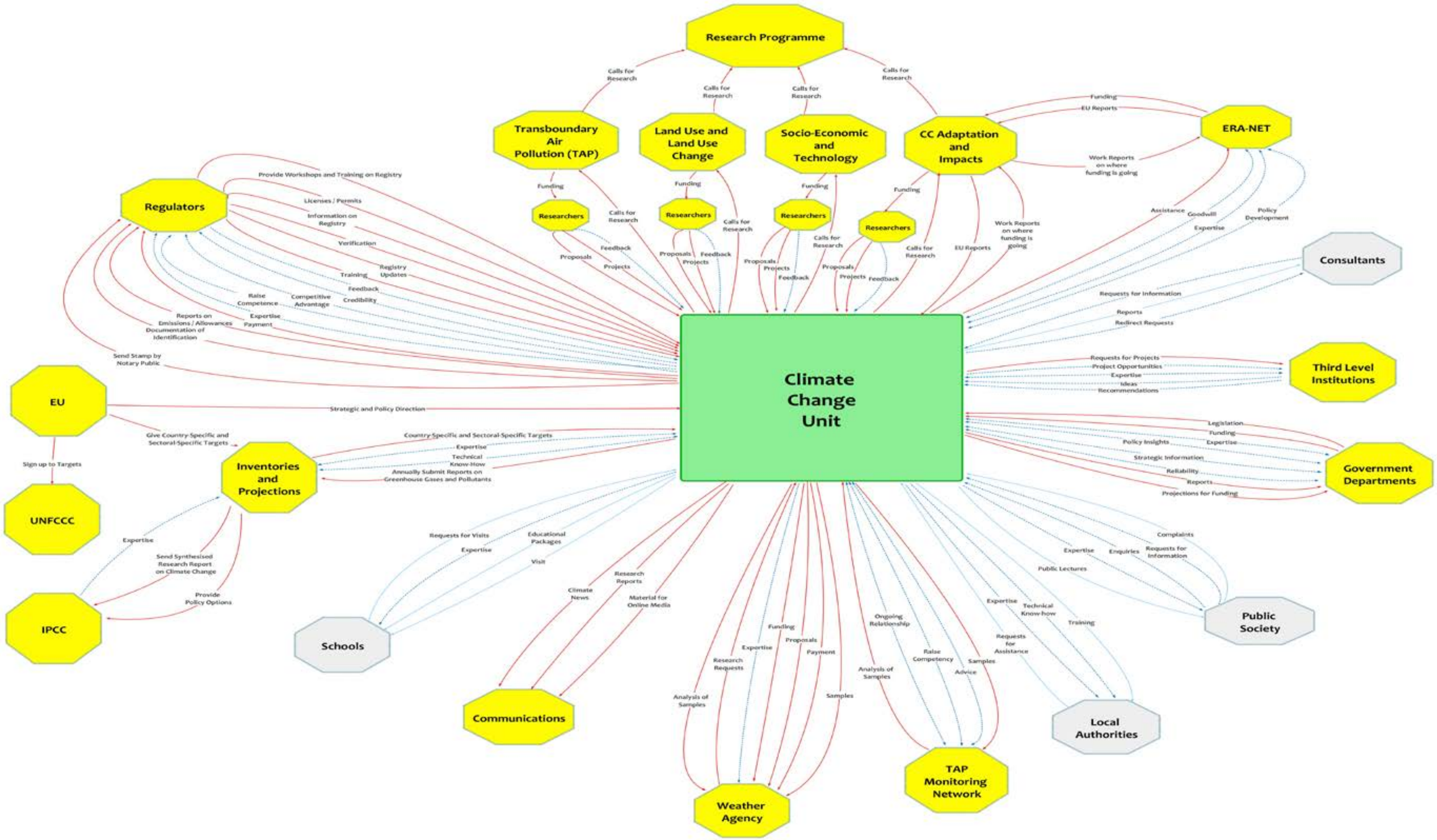
Participant D chose to be represented as a ‘Climate Change Unit’. The climate change unit is responsible for various environmental goals such as “*limiting and adapting to climate change; clean air; protecting waters; sustainability; and integration and enforcement*”. The climate change unit has twenty-one direct networks, of which seventeen are contractual and four are non-contractual, as seen in Table 6.2.4.0. Unlike previous maps, the climate change unit is heavily involved in mandated activity where contracts definitively guide the work of the unit. The climate change unit without funding, say “*the research programme would fall on its sword straight away because we couldn’t issue any calls for research*”. Research coordinates a large proportion of the work of the climate change unit, and integrates researchers from multiple disciplines such as Transboundary Air Pollution; Land Use and Land Use Change; Socio-Economic and Technology and the Climate Change Adaptation and Impact sector.

The climate change unit as a consequence of its contractual obligations is heavily involved in the exchange of tangible deliverables, as seen in Table 6.2.4.0. The tangible deliverables represent Katsamakas (2007) explicit knowledge and Choi and Lee’s (2002) systems knowledge where reports, projects, documentation and proposals are exchanged between networking groups. In addition, regulatory information such as directives and targets guide the national and international relationships of the climate change unit.

Table 6.2.4.0 Tangible Deliverables of Participant D

Participant	TANGIBLE DELIVERABLES			
	All	Impact Analysis	Value Creation	Both Impact and Value
D–Climate Change Unit	44	21	23	-

Figure 6.2.4 Value Network Map of Participant D



The intangible exchanges of the climate change unit represent a different format in that the majority of implicit and explicit exchanges relate to knowledge. Explicit intangibles include visits and educational material for schools as well as dealing with enquiries and complaints from the public "*who don't believe in climate change and don't believe it is happening*". Implicit intangibles relate predominantly to expertise and informal feedback mechanisms where groups associate with the climate change unit because of their reliability, credibility and dependability in environmental issues and sustainability.

Table 6.2.4.1 Intangible Deliverables of Participant D

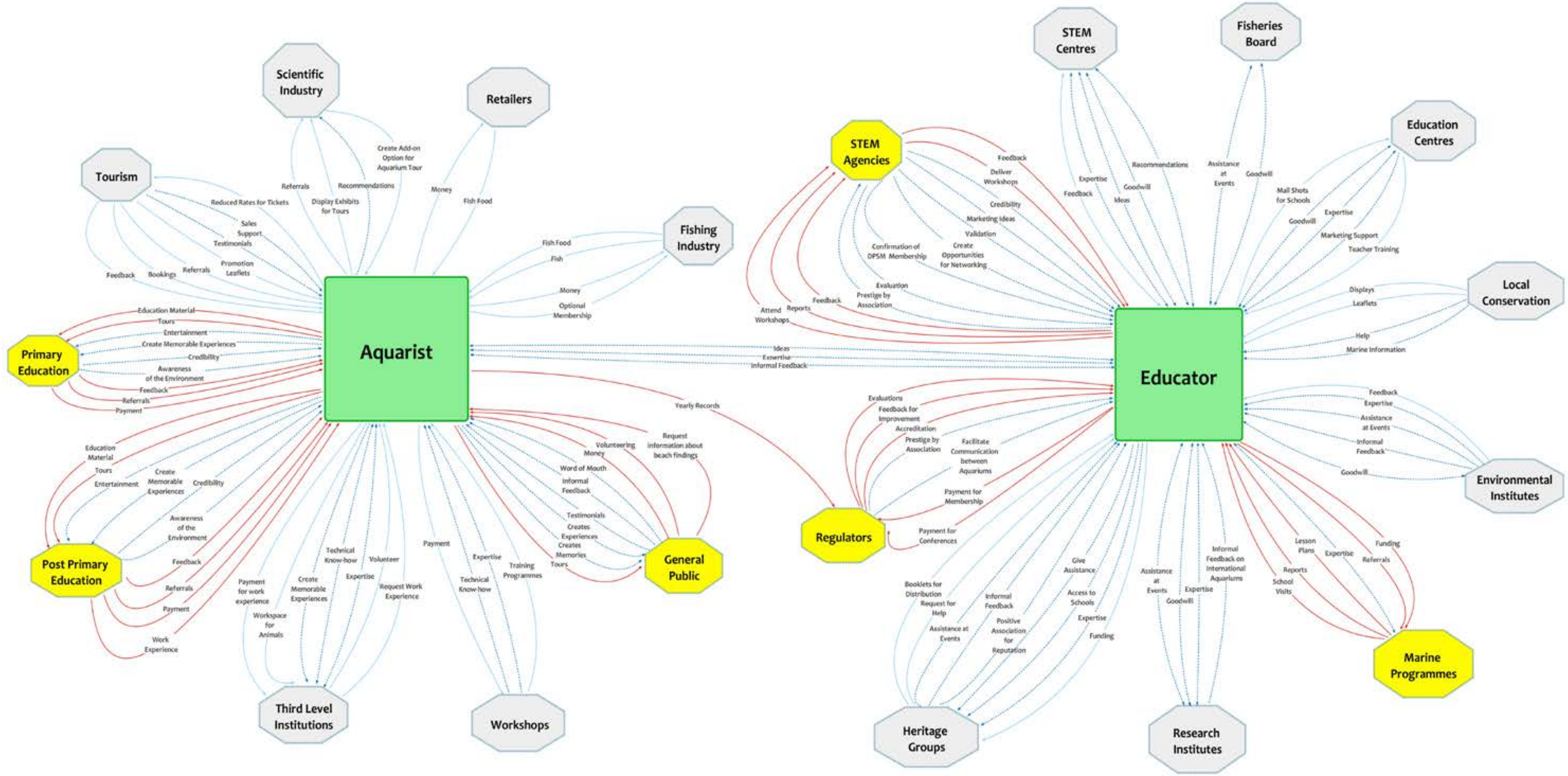
Participant	**INTANGIBLE DELIVERABLES**						
	All	**Impact Analysis**		**Value Creation**		**Both Impact and Value**	
		Explicit	**Implicit**	**Explicit**	**Implicit**	**Explicit**	**Implicit**
D–Climate Change Unit	42	5	10	3	11	-	13

6.2.5 Participant E

The value network map of Participant E includes two stakeholders from an aquarium. The map integrates the connections and groups of the entire organisation from the viewpoint of an educator and an aquarist. The educator in the aquarium works at the strategic level, networking with regulators, agencies, institutes, centres and local conservation and heritage groups. The aquarist works at the operational level of the organisation, engaging with the public, schools and suppliers of aquatic goods and equipment. The two roles, although formally divisive are central to the growth and sustainability of the aquarium.

In the value network map, there are nineteen networking groups, in which six of those groups are contractually mandated networks and the remaining thirteen networks co-exist through the development and cultivation of informal relationships.

Figure 6.2.5 Value Network Map of Participant E



The tangible deliverables for the aquarium render the services and materials exchanged for payments and funding. The "*bread and butter of the aquarium is the tours*" and these deliverables are the responsibility of the aquarist who engages with primary and post-primary schools and the general public daily, giving tours of the aquarium. The educator is formally responsible for the compilation of reports, lesson plans and evaluations. In addition, the educator is heavily involved in the accreditation of the aquarium; however, there is a joint responsibility on the part of the aquarium team to collectively assemble the yearly reports, visitor numbers and documentation needed by the regulators for evaluation and accreditation. This information is contained in systems and is explicitly stored and codified (Choi and Lee, 2002; Katsamakas, 2007).

Table 6.2.5 Tangible and Intangible Deliverables of Participant E

Participant	TANGIBLE DELIVERABLES			
	All	Impact Analysis	Value Creation	Both Impact and Value
E-Educator & Aquarist	21	8	12	1

Participant	INTANGIBLE DELIVERABLES						
	All	Impact Analysis		Value Creation		Both Impact and Value	
		Explicit	Implicit	Explicit	Implicit	Explicit	Implicit
E-Educator & Aquarist	73	7	15	8	18	2	23

The coordination of value creating outward deliverables is higher than the inflow of deliverables to the aquarium. However, the team believe that "*if you help someone for free, then they help you back for free*". This is reflected in the cultivation of the intangible networks of the aquarium. Relationships which are formed with local institutes and heritage and fishery groups' demonstrate goodwill relationships where networks provide assistance to one another at events, distribute leaflets and promotional materials, and provide referrals for other tourism bodies.

The aquarist and the educator depend on the creation of memorable experiences with children and students. Furthermore, intangibility for the aquarium relies on entertainment and word-of-mouth referrals, where a good experience can translate into repeated tours and increased visitor numbers. The process indicator of learning is prevalent in the aquarium as visitors learn about marine science through tours and the aquatic team learns how to give memorable tours and experiences to the public. Experiential learning captures the imagination of visitors, encourages loyalty and creates a consequential chain of informal referrals for the aquarium.

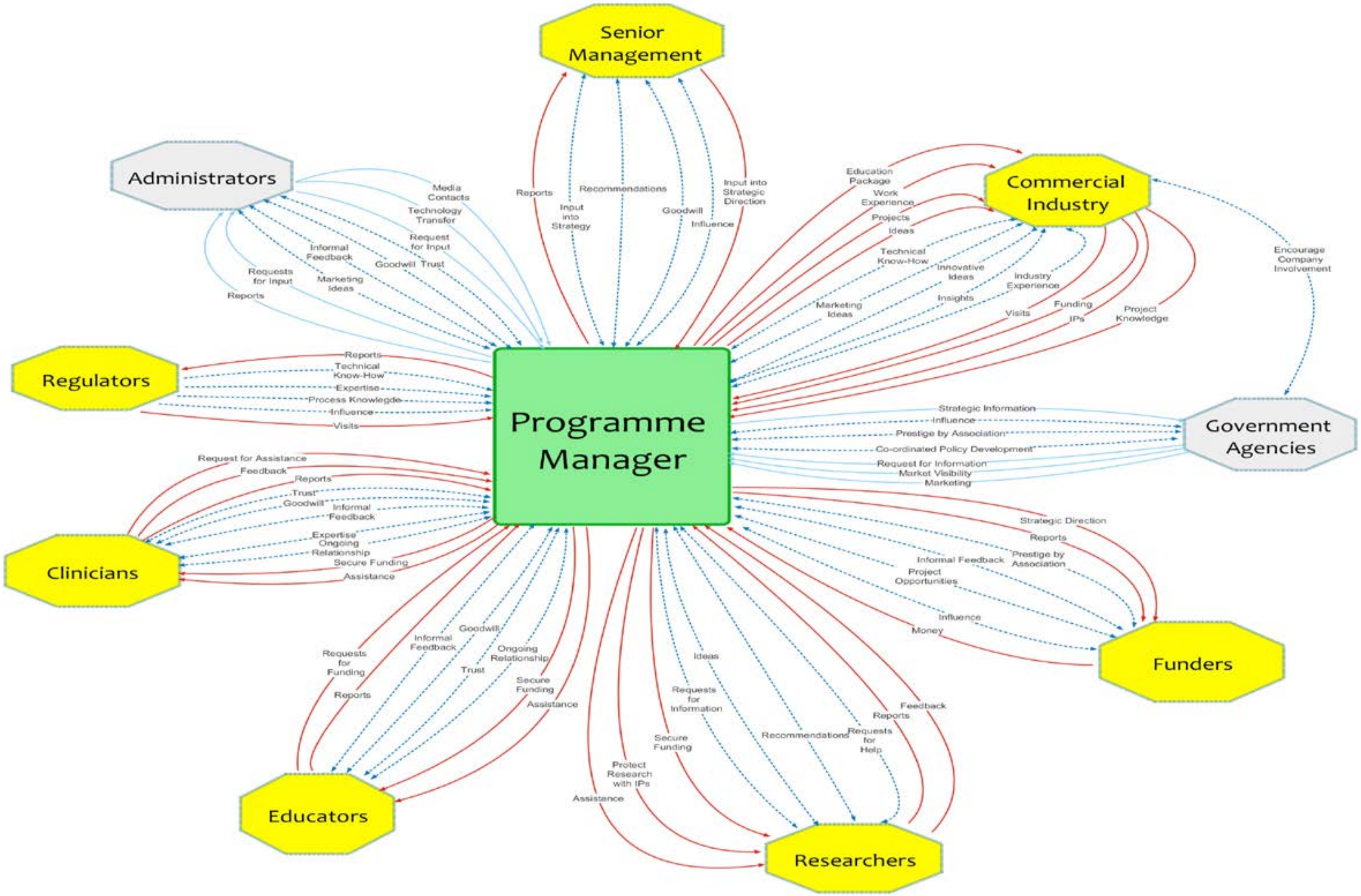
6.2.6 Participant F

Participant F assigned themselves the label of ‘Programme Manager’ in their value network map, as their role includes “*coordinating and managing activities for intellectual property management, graduate study programmes and outreach programmes*”.

In the value network map of the programme manager, there are nine networking groups. Like Participant D, the programme manager has more contractual than informal relationships. Specifically, the programme manager has mandated relationships with senior management, commercial industry, funders, researchers, educators, clinicians and regulators. The programme manager also has informal linkages with government agencies and administrators.

The strategic and operational work of the programme manager revolves around tangible deliverables. The programme director secures funding for educational research and protects the work and research of the organisation through IP’s received from commercial industry. In addition to funding and IP’s, the programme manager also evaluates formal feedback from clinicians and researchers. Furthermore, reports and projects represent a large portion of tangible exchanges for the programme manager, as the participant codifies written materials into useable and applicable formal documentation (Choi and Lee, 2002).

Figure 6.2.6 Value Network Map of Participant F



Reciprocity becomes a central tenet to the exchange of intangible deliverables for the programme manager, as illustrated in Table 6.2.6. Reciprocal intangibles relate to two dominant categories; knowledge and relationships. The programme manager and networking groups exchange ideas and expertise with one another. In terms of non-contractual relationships, groups connect with one another because of influence and prestige by association. Furthermore, goodwill and trust stimulate network formation and the facilitation of ongoing relationships.

Table 6.2.6 Intangible Deliverable of Participant F

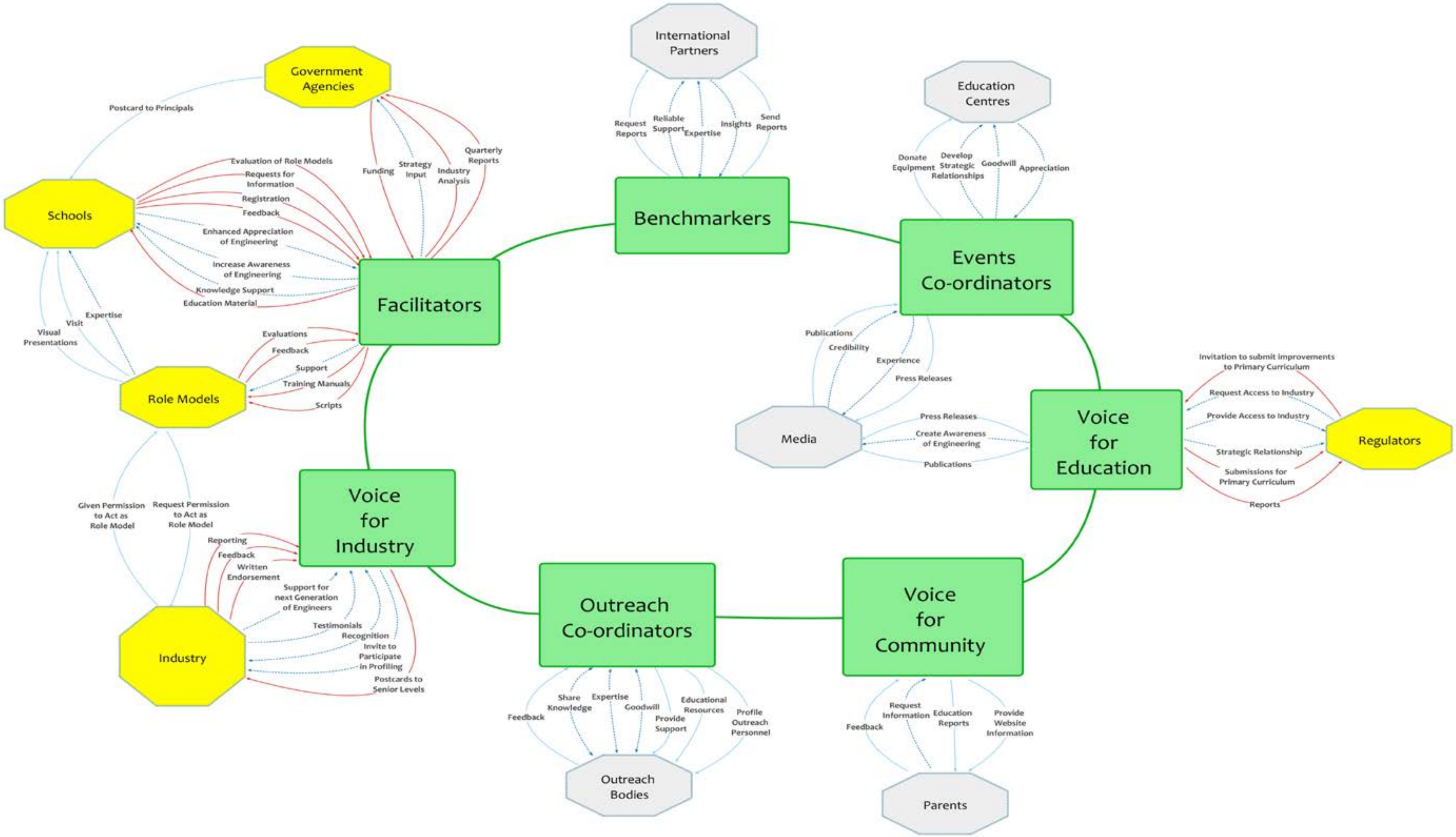
Participant	INTANGIBLE DELIVERABLES						
	All	Impact Analysis		Value Creation		Both Impact and Value	
		Explicit	Implicit	Explicit	Implicit	Explicit	Implicit
F- Programme Manager	46	6	4	3	-	-	33

6.2.7 Participant G

Participant G, as opposed to all preceding value network maps preferred to coordinate their map through their multiple roles in science communication. Participant G identified seven roles, as outlined in Figure 6.2.7, including benchmarkers, events coordinators, voice for education, voice for community, outreach coordinators, voice for industry and facilitators. The coordination of roles aligns with the target audiences of Participant G.

The value network map consists of ten networking groups where Participant G creates an ideological balance between contractual and non-contractual relationships. Contractual relationships occur with government agencies, role models, schools, regulators and industry. Role models are engineers who visit schools with visual presentations illustrating the importance and value of engineering to society, as well as promoting the discipline as a valuable career choice.

Figure 6.2.7 Value Network Map of Participant G



Although there is a balance between contractual and non-contractual network connections, the exchange of intangible deliverables outweighs the exchange of tangible deliverables for Participant G (39 > 19). Tangible deliverables include contracts, scripts, training manuals, formal invitations and other documentation which can be seen and traced throughout the organisation. Intangible linkages surround the exchange of expertise and support. Furthermore, implicit intangibles for Participant G emphasise the emotional orientation of science where awareness, appreciation, goodwill, reliability and credibility emerge as central constructs to the longevity of informal connections. More specifically, reputation and appreciation influence the choice of network partners and determine the sustainability of network partnerships for Participant G.

The next section of this chapter will collectively examine these seven value network maps through an exchange and impact analysis.

6.3 Value Network Analysis

The previous section outlined a reductionistic approach to VNA where special emphasis was placed on the networking groups of the science communicators. The individual value network maps were outlined and the tangible and intangible deliverables which are exchanged between science communicator groups were highlighted. The purpose of this section is to collectively analyse the maps from a holistic systems perspective where the "whole is greater than the sum of the parts" (Langlois, 1983, p.583). The findings from an exchange analysis are presented, which follow the format of five probing questions set out by Allee (2008) to facilitate exchange analysis. These probing questions were previously highlighted in the qualitative data collection instrument section (4.4.2) of the preceding chapter. In addition, the findings from an impact analysis outlining how specific value inputs are bringing value to each networking group are also presented (Allee, 2008). The next section will present the findings from the exchange analysis.

6.3.1 Exchange Analysis

VNA draws from exchange theory. However, VNA departs from mainstream exchange theory by "linking the network to both financial and non-financial performance and asset generation both for the network overall and at the level of the individual roles and transactions" (Allee, 2009, p.430). The deliverables which move between networking groups in VNA are emergent properties of a network and should not be treated in isolation as a system of micro-credits (Allee, 2008). Allee (2008) suggests that the analysis of exchanges between networks provides invaluable information on the overall patterns of exchange and value creation in a system, as well as outlining the relative health of a networking system.

There are five probing questions set out by Allee (2008) which assess the overall patterns of value exchange. Each of these questions will in turn be applied to the value networking system of science communication.

6.3.1.1 Is there a coherent logic and flow to the way value moves through the system?

Science communicators as is evidenced by the individual value network maps engage in bi-directional network exchanges where for the most part if "*if someone does something for us, we do something back*" (Participant E). Science communication literature from chapter two referred to one-way flows of information between upstream policy levels and the downstream public. However, science communication practice would suggest the flow of exchanges is bi-directional and mutually beneficial, as exchange involves a transfer of something tangible or intangible, actual or symbolic between two or more science communicators (Houston and Gassenheimer, 1987).

A finding which supports the science communication literature concerns the role of funders in science communication. Funders are partners in the networking system "*by necessity and not by choice*" (Participant F). Funders give money to science communicators in return for tangible documentation such as reports, projects and evaluations. The relationship between funders and science communicators parallels with restricted exchange where each actor gives and receives during the exchange transaction, reflecting the central economic principle of quid pro quo (Bagozzi, 1975). Alternatively, the flow of exchanges between science communicators and all other networking groups promotes a participatory orientation as the exchanges embrace interconnectivity, reciprocity and mutuality between science communicator groups (Hastings and Domegan, in press), rather than delineating exchange to be a self fulfilled prophecy of individualistic behaviour (Bagozzi, 1975).

The value networks maps illustrate a coherent logic to the way value moves as exchanges are bi-directional and multi-directional. Exchanges are not one-off episodes; exchanges develop and progress into reciprocal and mutually beneficial exchange relationships (Vargo, Maglio and Archpru-Akaka, 2008), as seen in the longevity of intangible and informal linkages between science communicators in the value network maps.

6.3.1.2 Does the system have healthy exchanges of both tangibles and intangibles, or is one type of exchange more dominant?

In the value network system, six of the seven respondents engage more heavily in intangible exchange relationships, as illustrated in Table 6.3.1.2. This is attributable to the co-existence of both contractual and non-contractual relationships between science communicators. The ratio calculations, except in the case of Participants D and F illustrate that intangible exchanges outweigh tangible exchanges by a two-to-one ratio. Participant D produces a balanced ratio scale between tangible and intangible exchanges.

Table 6.3.1.2 Science Communication Exchanges

Exchanges	Tangible Exchanges	Intangible Exchanges	Ratio
Participant A	31	84	1 : 2.7
Participant B	21	73	1 : 3.4
Participant C	26	56	1 : 2.1
Participant D	44	42	1 : 1
Participant E	31	91	1 : 2.9
Participant F	29	46	1 : 1.5
Participant G	19	39	1 : 2

These findings would suggest that intangible links and informal relationships guide science communication partnerships. This finding corroborates with the quantitative frequency counts of purpose for network involvement, where building connections with other STEM organisations ranked third among science communicators, preceded by keeping up to date with STEM activities and developments and access to STEM knowledge. Access to STEM knowledge deviates between tangible and intangible exchanges in the value network maps where science communicators' network with one another to gain access to published reports and documentation as well as intangible expertise, advice and insights.

6.3.1.3 Is there an overall pattern of reciprocity? For example, is one of the roles extending several intangibles without receiving a similar return?

Reciprocity is evident in all of the value network maps. Participant E maintains that "*we tend to get something back for everything we do*", while Participant B suggests that networking in science communication is a "*mutual win-win*". These mentalities illustrate the reciprocal mindset of science communicators as they enter into exchange relationships with a long-term orientation. Science communication practice corroborates with Robert's (2004) view in the literature, that interactive value processes satisfy mutual interests and facilitate co-learning resulting in win-win situations for the exchange actors.

Science communicators do not agree with the views of Buchanan, Reddy and Hossain (1994) in social marketing, who maintain that there is little consensus towards mutuality in complex exchanges as contributors are motivated by self-interested goals and manipulation. Science communicators, even in pursuit of self-interested motivations will always "*return the favour, if they can at a later stage*" (Participant B). This willingness between science communicators becomes "a fundamental basis of trust and thus, a long term relationship" (Chung, Singh and Lee, 2000, p.6). Reciprocity in science communication contributes to the nurturing of intangible relationships in the value network system, which as previously outlined outweighs contractual relationship exchanges by nearly 2:1.

6.3.1.4 Are there missing or dead links, weak and ineffective links, value dead ends, or bottlenecks?

Science communicators identified a series of links which need to be strengthened or created, as displayed in Table 6.3.1.4. These results conflict with the results of the online survey as survey respondents were asked to identify how often they communicate with their most effective STEM networks. In VNA, participants were given the opportunity to consider all their networking partners which allowed a more in-depth analysis of network ties spanning across strong, weak and dormant networks. Participants A, C, E and F identified groups which are missing from their network maps. These participants recognise that although these links are missing, the organisations can and do survive without these relationships. The creation of linkages with missing networks is difficult, as science communicators need to broker communication through established connections in their respective network maps. Participants recognise that they can only access their missing links through informal recommendations and referrals.

Table 6.3.1.4 Analysis of Links

PARTICIPANT	MISSING LINKS	STRENGTHEN LINKS	DIFFICULT LINKS	DORMANT LINKS
Participant A	Curriculum Authorities			
Participant B	None			Science Exploration Centre
Participant C	Patient Groups; Patients			
Participant D		Public Society; Local Authorires		
Participant E	SEAI	Third Level Institutions; Zoology Departments; Industry		
Participant F	Middleman between Organisation and Patient Groups; Patient Groups			
Participant G		Government	Parents	

Participants D, E and G identified groups within their networks that they would prefer to strengthen. The participants recognise that their current relationships with public society, local authorities, third level institutions, industry and the government are weak and that they need to allocate more time to nurturing and communicating with these connections. Participants D and E identified intangible groups as their weak link whereas Participant G identified a contractual link as weak.

Participant G also stated that parents are a difficult group to connect with as they are not as visible as students, schools and the public. Parents normally contact Participant G with formal requests for information and expert advice. Participant G would like to manage this relationship better and pre-empt parents concerns and queries. Presently, the website of Participant G is the direct source of contact with parents, but the group would prefer to coordinate a pro-active dialogue process with parents, rather than a reactive process of answering questions, concerns and complaints.

Participant B was the only participant to identify a "*dormant network*". The development of a science exploration centre lacked appropriate funding from government and could not progress from the conceptualisation of an idea to a structural component within science.

6.3.1.5 Is the whole system being optimised, or are some roles benefiting at the expense of others?

Participants recognise that the system of science is reciprocal. However, there are priority relationships or heart links in the value network maps. These heart links represent organisations which science communicators could not operate without. These heart links are represented in Table 6.3.1.5. Heart links are primarily associated with contractual relationships where formal contracts and agreements mandate the activities of science communicators. Heart links fall into two categories; groups which give funding to science communicators and the target audiences or recipients of science information, knowledge and products.

Table 6.3.1.5 Heart Links in Science Communication

MAP PARTICIPANT	HEART	SECOND HEART
Participant A	Primary Schools; Post-Primary Schools; Education Centres	Bio-Medical Sector; IT Sector
Participant B	ALL	
Participant C	Funders	Public Society
Participant D	Funders	Research Programme; Transboundary Air Pollution
Participant E	Primary Education; Marine Programmes	
Participant F	Funders	Commercial Industry
Participant G	Government Agencies	Schools; Industry

Participant B noted that all its networking groups were important. "*I don't work with people I don't want to work with*" (Participant B) and hence, each and every relationship, albeit tangible or intangible creates new "*conversational crossover networks*".

In summary, the assessment of exchanges in science communication illustrates that value exchanges are reciprocal and mutually beneficial. This finding supports the strong agreement for exchange in the online survey as well as Bagozzi's (1975) concept of complex exchange in the literature where collective and relational exchanges shift the orientation from short term transactions to the complex formation of value systems (Juttner and Wehrli, 1994). In practice, science communicators coordinate and participate with one another over the long-term, as opposed to creating short term win-lose situations. Furthermore, science communicators convey a dual interest in science communication where they want to see their individual organisations do well, but they also want the holistic system of science communication to operate effectively to increase the awareness of, support for and participation in science whilst also influencing school subject, degree and career choices (Davison et al., 2008). The next section presents the findings from the impact analysis in VNA.

6.3.2 Impact Analysis

An impact analysis assesses how specific value inputs are bringing value or benefit to each role, whilst also assessing the overall tangible and intangible cost/benefit for each value input (Allee, 2008). An impact analysis also shows whether a science communicator is realising value from the deliverables it receives and the deliverables it exchanges with other science communicator groups in the value network. Table 6.3.2 outlines the impact analysis of the science communication system in terms of the exchange classification, the channel of communication, the speed of transactions and the overall impact for the science communicator as receiver and sender.

Table 6.3.2 Impact Analysis

Participant	A	B	C	D	E	F	G
Exchange Classification							
Competence	75	42	48	47	56	38	36
Structure	6	11	5	18	15	15	5
Business Relationships	33	41	29	10	51	22	14
Channel of Communication							
Face to Face	91	70	57	51	108	59	31
Email	10	7	10	10	3	8	15
Email / Phone	7	1	13	10	2	1	4
Online	-	6	-	-	-	-	-
Online / Print	-	2	2	-	-	-	-
System	5	8	-	4	9	7	2
Media	1	-	-	-	-	-	1
N/A	-	-	-	-	-	-	2
Speed of Transaction							
High	87	47	69	47	67	42	29
Medium	22	26	10	28	29	20	26
Low	5	21	3	-	26	13	-
Impact for Science Communicator							
Cost (as sender)	1	4	1	4	9	-	2
Cost (as receiver)	-	4	2	3	2	2	2
Benefit (as sender)	73	60	45	47	48	53	31
Benefit (as receiver)	40	26	34	21	67	20	20

The classification of exchange in VNA is based on the Intangible Assets Monitor of Karl-Erik Sveiby consisting of three asset categories of ‘human competence’, ‘internal structure’ and ‘external structure’. In VNA, external structures relates to business and social relationships (Allee, 2008). In the case of science communication, participants are motivated to network with other organisations to increase their competencies. This finding also correlates with the finding from the online survey as science communicators networked in order to stay abreast of scientific developments in addition to gaining access to STEM knowledge in the industry. Structural exchanges in science communication are strongly associated with regulatory and funding bodies, as payments and accreditation allow organisations to operate. Business relationships are primarily associated with intangible relationships as Table 6.3.2.1 outlines. Furthermore, business relationships in the context of science communication are based on social and informal connections between participants where goodwill, reliability and trust co-exist.

Table 6.3.2.1 Exchange Classification Breakdown

	Contractual Exchanges		Non-Contractual Exchanges	
All Participants	**Tangible**	**Intangible**	**Explicit Tangible**	**Implicit Intangible**
Competence	107	86	74	75
Structure	57	3	15	-
Business Relationships	29	60	40	71

The most cited channel of communication in value network maps was face-to-face communication with email methods coming in second. These findings conflict with the online survey findings as respondents to the questionnaire cited online methods as the most important form of contact with STEM organisations. Face-to-face communication ranked third after conferences.

The speed of transactions relates to the timing of relationships. Relationships which are extended over a period of time are represented by ‘medium’, and long-term relationships are represented by ‘low’. The majority of transactions in science communication are high and occur over a short period of time. All participants engage in short-term and medium-term relationships. Participants D and G are the only science communicators who do not engage in long-term relationships with other science communicators and these two organisations provide inputs to science policy.

Science communicators assign their exchanges and relationships as benefits rather than costs. Structural exchanges account for the majority of costs where payments are made for goods, services, knowledge and equipment. Time was considered another cost, as responding to queries and requests in addition to providing work experience took time away from the everyday duties of the science communicators.

In relation to the impact analysis, science communicators realise high value benefits from the exchange of tangible and intangible resources and deliverables. Science communicators through network involvement, participation and exchange increase competency, develop business and social relationship ties and sustain internal structures and operations.

The remaining section of this chapter integrates the findings of VNA with the literature on the process indicator categories of knowledge, networks, intangibles and system dynamics.

6.4 Discussion

The qualitative phase to this study examined how value is created and exchanged between science communicators through VNA. VNA sequentially examined the process indicator categories of knowledge, networks, intangibles and system dynamics and measured the overall pattern of exchange and value creation in science communication. VNA also analysed the best way to create, extend and leverage value between science communicators (Allee, 2008). The remainder of this section links the findings from the sequential phase of this qualitative research to the literature on the four process indicator categories.

6.4.1 Knowledge

In the literature, Choi and Lee's (2002, p.176) definition of knowledge generation classified it as a "continuous process, whereby individuals and groups within a firm and between firms share tacit or explicit knowledge". Katsamakas (2007) in the innovation literature also supports the generation of both explicit and implicit knowledge. The generation of explicit and implicit knowledge from the literature is comparable to the aggregated tangible (continuous red line) and intangible (broken blue line) generation of knowledge from the seven participants of VNA, as illustrated in Figure 6.4.1.

Figure 6.4.1 An Aggregated Map of Knowledge Generation in Science Communication

More specifically, Katsamakas' (2007) generation of explicit knowledge from the innovation literature is comparable to the aggregated tangible and explicit generation of knowledge in VNA; including reports, projects, educational material, feedback, manuals, scripts, marketing documentation and official company documentation. Alternatively, tacit knowledge is harder to identify as it resides in the minds of science communicators. Katsamakas' (2007) generation of tacit knowledge from innovation theory is evident in the exchanges of expertise, advice, ideas, insights and informal feedback through intangible deliverables in VNA. The collective generation of tacit knowledge relies heavily on informal network connections and relationships, as science communicators feel comfortable generating knowledge with industry colleagues in comparison to new network partners. Knowledge generation in VNA combines both self-interested motives and mutual gain. The literature however, suggests that the transfer of information stems from mutual antagonism and manipulation (Buchanan, Reddy and Hossain, 1994) or consensus and mutuality (Tabanico and Schultz, 2007). VNA interlinks both motives stating that although there can be a short-term element to self-interest; science communicators "*tend to give something back*" (Participant E) and display mutually beneficial exchanges over the lifetime of their relationships.

Knowledge transfer in the literature was defined as a "unidirectional and logical flow of information from knowledge producers to knowledge users" (Jacobson, 2007, p.117). Knowledge transfer clearly demarcates the boundaries between parties as individual roles were assigned to producers and users of information. Knowledge transfer in VNA was evident in all of the value network maps as very often, transactions were unidirectional. The transfer of knowledge in VNA differs from the underlying premise of knowledge transfer in the literature, as Roberts (2000) suggests that knowledge transfer embraces a hierarchical authoritative strategy where few stakeholders are involved, and the transmission episode is quicker and less contentious than a cooperative strategy. In VNA, authority does not impact or influence the transfer of information between science communicators. In fact, equality plays an important role between science communicators and their network partners and for all intensive purposes; they are equal contributors to the system of science communication. Science communicators are differentiated by their roles in the communication of science; however the outcomes of these individual roles are the same, in that science communicators want to increase the public awareness of, support for, and participation in science (Davison et al., 2008). The practice of equality in science communication corroborates with the view of Roberts (2004) who suggests that equality empowers each level in their roles as advocates, consumers, volunteers, co-producers and co-learners (Roberts, 2004).

Knowledge exchange means "interactivity, engagement and a propensity to act on both sides. Knowledge exchange is more than listening; it implies shared learning and communication between equal problem solvers" (Prahalad and Venkat, 2004, p.6). Knowledge exchange is hugely important in VNA as the longevity and cultivation of long-term network partnerships is underpinned by knowledge exchange. Knowledge exchange in VNA is not limited to one type of relationship. Knowledge exchange occurs in both contractual and mandated relationships as well as informal and non-contractual relationships. In the literature, Logan (2001) suggests that knowledge systems become multi-directional as transmission works both ways to integrate knowledge, ideas, attitudes and beliefs (Jackson, Barbagallo and Haste, 2005). VNA integrates reciprocal knowledge exchange and unidirectional knowledge exchange. As was previously discussed, long term partnerships in VNA do not necessitate an instantaneous quid pro quo element, instead knowledge favours and knowledge exchange can be returned at another point in time, when assistance or help is requested by the partnering organisation.

6.4.2 Networks

In the literature, network involvement "investigates the composition of the network – the identities, status, resources, access and other characteristics of the focal industry's alters and other nodes" (Gulati, Nohria and Zaheer, 2000, p.205). Network involvement in VNA is highly relevant as each of the value network maps displays a high proportion of network involvement in science communication. Science communication in Ireland depends on network involvement. Participant B in the value networks even finds that "*you're connecting people that don't even know each other*" because "*there's a conscious networking aspect*" to science communication.

Participant E also noted that "*if you're not involved a lot with a group, the prestige by association is so important that the value of involvement is high because without them … we would suffer*". Science communication practice associates with the thinking of Parung and Bititci (2006) who contest the exploitative nature to network involvement, defining it as a means of working together for mutual benefits. Value networks in science communication conflicts with the literature of Katsamakas (2007) who is the only author to depict network involvement duration as being built on short term exchange episodes. In VNA, network involvement arises from "*informal conversations which end up developing and just connecting over time*" (Participant B).

Network ties are defined by Kramer and Well's (2005, p.430) as "connections between people which can be relatively tenuous (weak) or intensive (strong) depending on the frequency, intensity, intimacy and reciprocity of the interaction and connection". Network ties represent invaluable proponents to the analysis of a value network map. In the above analysis section, weak links were identified by each of the participants in terms of those networking groups which are absent and those which are difficult to network with, as well as the connections and ties that need to be strengthened. In VNA, strong networks are represented by heart links which without their cooperation, involvement and participation, the science communication organisations would cease to exist. In science communication, due to the size of the industry and the country, networks are predominantly strong and there is a huge sense of comradeship between science communicators who "*just make things happen and get things done*" (Participant B).

Network position is measured through centrality – the degree to which an organisation is directly or indirectly connected to other organisations and the degree to which other organisations are connected through it (Tsai, 2001; Hardy, Philips and Lawrence, 2003). In VNA, network position was not important to the science communicators in comparison to networking with the most productive and reliable STEM organisations. Network position is hard to identify in VNA as there are "*networks within networks*" (Participant B). Science communicators preferred to view their role in science communication as being equal to their STEM counterparts. However, participants were able to identify the central position of their heart links, as these priority groups secured funding, payments and accreditation for the science communicators.

6.4.3 Intangibles

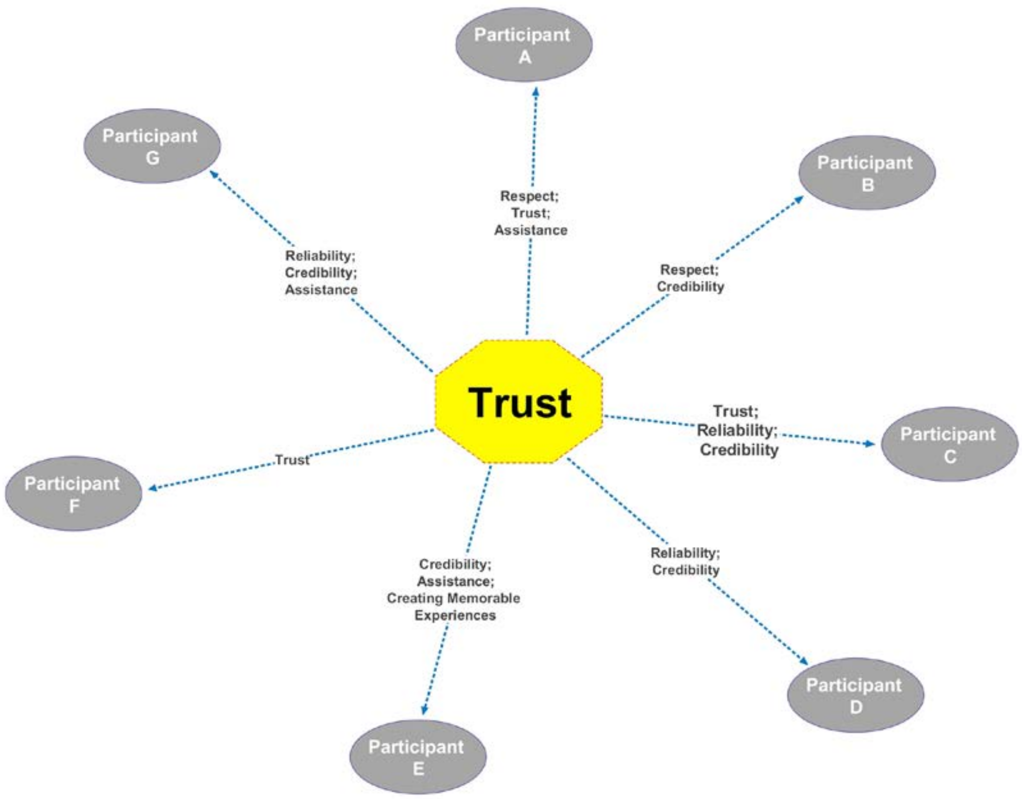
The definition of trust guiding this research states trust occurs when "both partners share similar values, when communication in their relationship is healthy and when their relationship history is not characterised by one partner maliciously taking advantage of the other" (Hunt and Morgan, 1994, p.24). Furthermore, trust in the literature is about firms co-operating in a manner which is not malicious, spiteful, opportunistic, or indeed that will not impact negatively on the relationship between partners in a network (Hunt and Morgan, 1994; Achrol, 1997; Batt and Purchase, 2004).

In practice, trust is about "*competency and professionalism and technical ability*" (Participant F) where it's "*more bona fide beneficial*" (Participant A). Science communicators trust that their networking partners will operate and connect in a non-malicious manner. However, Participant A states that although:-

> "*I would have a high level of trust with everyone in my map, I have experience that when I go to meetings and have discussions with other centres, you can see that I have no problem answering any question telling people exactly how it is at the aquarium because we're all in the same boat, you know trying to make a living but you can see certain centres that don't want to tell how many visitors they've had, don't want to say how many schools they get and give the most wishy-washy answers – all very vague because people feel you're in competition with them*".

As a consequence of competition, both Participant B and F state that trust "*needs to be managed*" to protect science communicators from malicious and opportunistic players in STEM. Furthermore, three out of the seven participants from VNA identified reliability as an important antecedent to a trustworthy relationship, as seen in Figure 6.4.3. As the reliability of a science communicator gains momentum and acknowledgment, it results in repeated network exchanges and progresses into win-win trustworthy relationships and referrals. At an aggregated level, six of the seven participating organisations treat respect, reliability, assistance and credibility as synonymous with the concept of trust in practice. Participant F was the only participant who out rightly stated they have trust in their networking partners, given this participant strategically manages trust throughout their networking relationships.

Figure 6.4.3 An Aggregated Map of Trust in Science Communication



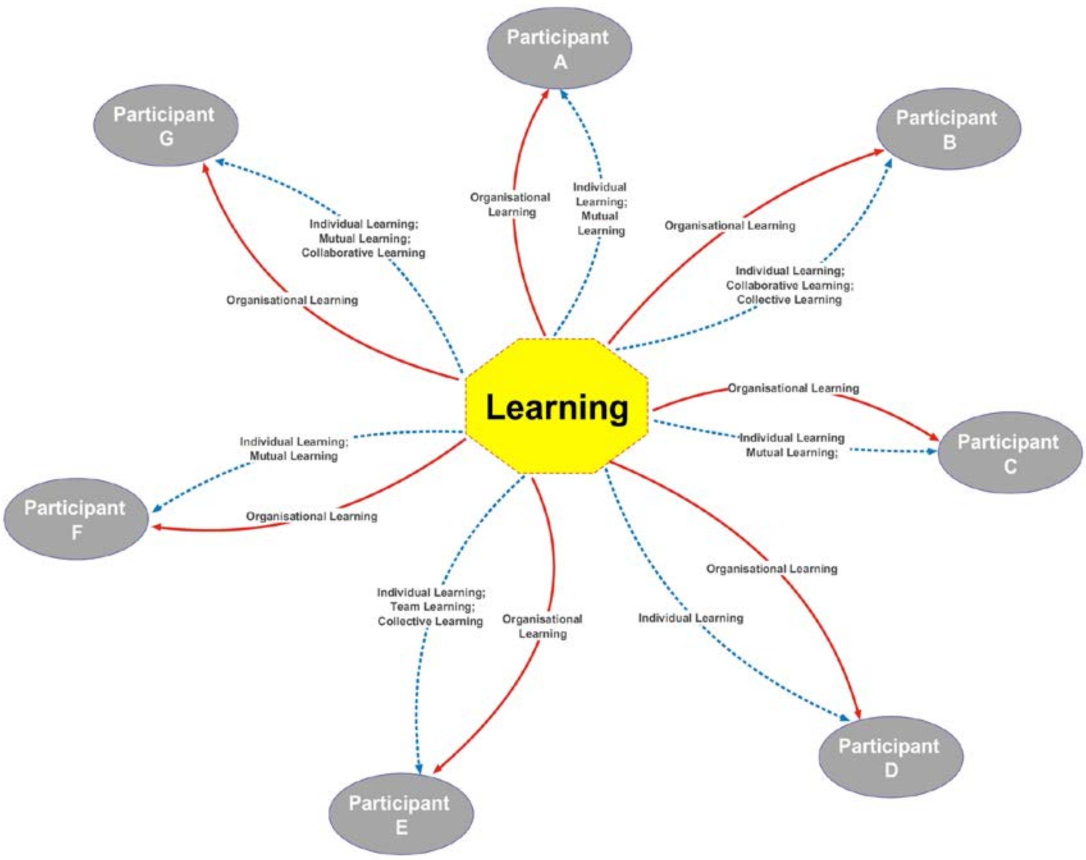
Commitment was conceptualised by Kramer and Wells (2005, p.430) in the literature as “creating strong links through direct connections and ongoing relationships which are built through repeated, sequential forms of interaction and obeying the rule of reciprocity, which evolve into a common understanding of mutual commitments and trust in the goodwill of others”. Ongoing relationships, which represent a form of commitment, were identified by Participant A and Participant B, while Participant C referred to commitment as a consistent relationship in addition to a form of goodwill, as seen in Figure 6.4.3.0.

Figure 6.4.3.0 An Aggregated Map of Commitment in Science Communication

At an aggregated level of science communication, goodwill emanated as an important exchange deliverable for six out of the seven participants, as the exchange of non-contractual resources and knowledge relies on the goodwill of networking partners. Science communicators are not only committed to their individual silos of knowledge and role activities, but they are also committed to the holistic system of science communication in order to create a positive image of science with students, the public, teachers, industry, policy makers and regulators at both national and international levels. Participant D who works at the science policy level, did not view commitment as an important antecedent to the continuance of their networking relationships, as the climate change unit is heavily involved in the contractual exchange of tangible deliverables to meet regulatory guidelines, directives and targets.

Learning in chapter three highlighted the construct as complex and multi-dimensional (Hult and Ferrell, 1997) because learning can be deconstructed into individual learning (Davies et al., 2009); collective learning (Cotic-Svetina, Jaklic and Prodan, 2008); mutual learning (Hastings and Domegan, in press); organisational learning (Katsamakas, 2007) and interactive learning (Mu, Peng and Love, 2008). In practice, learning is also viewed as a multi-dimensional construct as reflected in the aggregated learning map in Figure 6.4.3.1. All seven participating organisations viewed organisational learning as contractual (continuous red line). Beyond organisational learning, there is an element of self-fulfilment in learning, as individuals like to take away new knowledge, insights and ideas from their informal networking relationships (broken blue line). Participant D; the climate change unit representing the policy level of science exhibits individual and organisational learning, but are not committed to mutual, collective and collaborative learning. The remaining six participants (A; B; C; E; F and G) through their informal partnerships and linkages exchange knowledge to benefit both parties and build upon their respective knowledge sets, ideas and skills within science communication.

Figure 6.4.3.1 An Aggregated Map of Learning in Science Communication



In essence, science communicators in practice exhibit every facet to learning facilitating "information acquisition, information dissemination and shared interpretation" (Hult and Ferrell, 1997, p.98). The only criticism surrounding learning was highlighted by Participant A which identified that "*there's little project based learning*" in science communication. However, this criticism relates to the science education curriculum and not the everyday work of science communicators.

Reciprocity as outlined in the literature "reduces the uncomfortable feeling of indebtedness" (Tabanico and Schultz, 2007, p.43). Reciprocity is a fundamental concept within VNA and is evident in each of the value network maps, as science communicators embrace mutually beneficial relationships (Marques and Domegan, 2011; Hastings and Domegan, in press). Organisations which were identified to have medium value benefits in the impact analysis were identified as organisations that "*are so busy, they don't have the time to give a lot back*" (Participant E). Science communicators are appreciative of the roles and activities of their fellow networking partners, realising that quid pro quo reciprocity occurs throughout the course of a long-term relationship as opposed to instantaneous ingratiation. This finding extends both the concept of exchange and reciprocity in the three streams of literature.

6.4.4 System Dynamics

Governance in the literature relates to "how authority is exercised and how actor relationships are organised to overcome the resistance of actors to participate in coordination" (Braun, 2008, p.292). The science communication literature is burdened by the protraction of hierarchical and autocratic control systems of communication (McGuire and Olson, 1996; Swyngedouw, 2000). However in practice, science communication exhibits collaborative and participatory systems of governance.

Science communicators who work at the heart of policy coordination refused to participate in the VNA process. Several key policy organisations were contacted but again refrained from participating in the value mapping exercises. This response could be interpreted as a hierarchical position where policy makers exhibit a closed system of governance and the participants' exhibit open systems of coordination.

However, this assumption must be taken with caution as policy makers did not comment on the system of science or its governance.

Lundvall (2007) associates a balance to network governance where modes of centralisation and decentralisation are mixed. The relationships between participants in the value network maps embrace openness and closed innovation simultaneously. Science communicators such as Participant C and F have a responsibility to protect the work of their organisation through intellectual property and contracts. Participant F states that "*it's not that we don't trust our networking groups, it's that we're careful … and that's where the contract comes in to make sure that both sides are protected*". Governance in the value networks maps emphasises openness and transparency between science communicators which influences subsequent network interactions and word-of-mouth referrals between STEM organisations.

6.5 Chapter Summary

This chapter presented the findings from the qualitative phase of the sequential explanatory study. Seven value network maps were highlighted illustrating the tangible and intangible exchanges between science communicators. In addition to presenting the reductionistic micro maps of the science communicators, a holistic analysis of the system of science was also given through the collective exchange and impact analysis of the seven network maps. Network involvement, connections and ties are extremely important to all seven science communicators, Furthermore; reciprocal exchange relationships are underpinned by equality in science communication, as participants embrace goodwill, transparency, mutuality and collaboration. Following the analysis of the value network maps, the chapter concluded with a discussion which linked the process indicators from the literature review with the findings of the value network analysis.

All three phases of the sequential explanatory research methodology are now complete. The next chapter will discuss the conclusions and implications of this research and suggestions for future research.

Chapter Seven: Conclusions and Recommendations for Future Research

7.0 Introduction

Science communication is a complex process (Manzini, 2003). In the literature, science is viewed as static and evolutionary as opposed to a dynamic and inter-related process of mutually interconnected interfaces and paradigms (Trench, 2008). Science communication; to affect progressive change and the need the move upstream (Wilsdon and Willis, 2004) must move beyond the constricted focus of the recurring deficit model and concentrate on the integrative understanding of both open and closed participatory processes in science communication (Stirling, 2008). The integration of science communication with social marketing and innovation theory extends the analytic understanding of participatory processes whilst also assisting in the development of process indicators for science communication.

Process indicators provide effective measurements of the elements that stipulate and shape participation in science communication (Dodgson and Hinze, 2000). This recognition however, is inhibited by a lack of empirical research relating to process indicators in science communication. The lack of evidence supporting a consensus model of process indicators causes ambiguity in science communication, as the literature continues to revisit the counter arguments between informing and mutual learning models in science communication (Van der Hove and Sharman, 2006). This study outlines how an interdisciplinary approach to science communication, using social marketing and innovation theory provides a better understanding of participatory processes through the development of process indicators for science communication. The purpose of this chapter is to discuss the key findings and conclusions arising from the investigation into the primary research question and secondary objectives of this research.

7.1 Conclusions

The conceptualisation and measurement of process indicators in this study was theoretically guided by the primary research question and secondary objectives. The collective coordination of responses and findings to these foundational questions are outlined within this section.

7.1.1 Secondary Objectives

Secondary Objective 1 specifically related to the paradigms in science communication. Two parts to this objective were devised; one theoretical and one empirical, as respectively discussed below:

(i) To delineate the different science communication paradigms.

Four dominant paradigms have emerged and co-exist within the science communication literature. These paradigms consist of science literacy; the public understanding of science and the science-and-society and science-in-society paradigms. Each of the four paradigms have borne with them certain traits, characteristics, attributions, ideologies and orientations, as summated in Table 7.1.1.

7.1.1.1 The Science Literacy Paradigm

The science literacy paradigm was overtly consumed by the need to increase the scientific literacy levels of the general public. The scientific community identified education as the optimal solution to this implicit social challenge. During this paradigm, scientific information was transmitted from experts to lay audiences who were deficient in their awareness and understanding of all things scientific. This deficiently attributed a knowledge deficit to an insufficiently literate public, where the public were seen as passive and sometimes poorly qualified receivers of scientific knowledge. The oversimplified judgements of the upstream policy and science communities resulted in the creation of a hierarchical and linear model of communication between science and the public.

Table 7.1.1 Summary of Dominant Science Communication Paradigms

Periodisation of Irish Science Communication	**Period of Discovery (1950 – 1970s)**	**Period of Conceptualisation (1980 – 1990s)**	**Period of Enlightenment (2000 – Present)**
Science Communication Paradigms	**Science Literacy Paradigm**	**Public Understanding of Science Paradigm**	**Science - and / in - Society Paradigms**
Attribution Diagnosis	Public Deficit Knowledge	Public Deficit Attitudes	Trust Deficit Expert Deficit
Communication Model	Dissemination; Education	Dialogue	Conversation; Engagement
Ideological and Philosophical Assumptions	Scientism; Technocracy	Pragmatism; Constructivism	Participatory democracy; Relativism
Communication Style	One-way; Top-down	Two-way, Bottom-up	Multiple Stakeholders; Multiple frameworks

Adapted from: Bucchi (2008); Irwin (2008); Trench (2008); Bauer (2009)

7.1.1.2 The Public Understanding of Science Paradigm

The public understanding of science paradigm unlike science literacy shifted from an autocratic presumption of identifying what the public ought to know, to a dialogical process of establishing what the public wants to know and finding ways to make this knowledge available and accessible (Borchelt, 2001). In essence, this paradigm emphasises the communal sharing of information (Leach, Yates and Scanlon, 2009), as the public are viewed as contributors to the multi-directional process of science communication, rather than the laity (Logan, 2001). The move from deficit to dialogue presented new challenges for the science community as the public's understanding of science was no longer burgeoned by the issue of whether one was literate or illiterate, but more or less knowledgeable (Bauer, 2009).

7.1.1.3 Science and / in Society Paradigms

The science-and-society and science-in-society paradigms represented a period where upstream policy and science communities attempted to eliminate the paternalistic, top-down hierarchical approach to science communication and open the process to a 'new mood for dialogue' (Gregory and Miller, 1998). During this paradigm, participation was highlighted as non-restrictive in that the nature of the communication process was not delimited to the scientist as sender and the public as receiver (Leach, Yates and Scanlon, 2009). In fact, the participatory orientation of this paradigm acknowledges mutual learning and communication between the multiple levels of science, where participation or input can make a difference (Glicken, 1999).

These four paradigms suggest that as science communication progressed, upstream stakeholders became more cognisant of the hierarchical and authoritarian boundaries between upstream policy and practice levels with the downstream public. The deliberative shift from deficit and dialogue to participation in science communication recognises the emerging role of issue driven science; which looks towards solving societal problems and policy, practice and public levels become oriented towards action and change (Van der Hove, 2007). The implication of these four paradigms in science communication did not undergo empirical testing but this study integrated the three levels of policy, practice and the public with the four paradigms to contribute to, and deepen the understanding of participation and participatory processes in science communication.

(ii) To understand the roles of science communicators in the process of science communication.

The three phases of this sequential study sought to understand the roles of science communicators. In the literature, three overarching roles were presented relating science communicators to policy, practice and public level science (Glicken, 1999);

Weigold, 2001; Lujan and Todt, 2007). The quantitative phase of this research presented four definitive roles within science communication, where the policy level of science was represented by those who directly influence science policy and those who influence the science education curriculum, as seen in Table 7.1.1.0.

Table 7.1.1.0 Science Communication Roles

Role	Frequency	Percentage
Encouraging Science Education in Schools	33	24.4%
Engaging in Science Outreach with the Public	27	20.0%
Influencing the Science Education Curriculum	13	9.6%
Influencing Science Policy	27	20.0%
Other	35	25.9%

The response towards the ‘other’ category came to the attention of the researcher, as respondents served multiple roles in science communication simultaneously. The qualitative phase of this research allowed the researcher to explore the roles in science communication in greater detail, as VNA required participants to define their specific roles. Science communication roles are not mutually exclusive as the science communication literature portrays. Glicken (1999), Weigold (2001) and Lujan and Todt (2007) conceptualise that science communicators possess static and well-defined roles in science when in practice; science communicators serve a multiplicity of roles at varying levels of science communication.

Science communicators work in one specific role daily and enhance that role by influencing, contributing to, and mediating between science-and-policy, science-and-practice and science-and-the-public. This finding extends the total market approach in the social marketing literature (French, et al., 2010; Hoek and Jones, 2011; Lefebvre, 2011) and the multi-dimensional view in innovation theory (Nonaka, 1994; Nonaka, Toyama and Konno, 2000) where stakeholders from multiple levels across multiple disciplines co-create value. In practice, science communicators work across multiple disciplines at multiple levels of science co-producing scientific knowledge and co-creating experiential change.

Secondary Objective 2: To establish the key science-policy interfaces in science communication.

Chapter two articulated that science communication and public policy interfaces are social processes that have become interwoven in a longstanding relationship which is fraught with complexity and uncertainty, as the gap between science and policy widens (Bradshaw and Borchers, 2000). The European Commission (2009) accentuated the importance of the science-policy relationship, stating that if policy makers are not available to the scientific community or the channels of communication are not opened, then policy makers will be unable to make the best decisions on tough challenges facing an economy. The literature in science communication lacks a consensus-based science-policy interface model. Consequently, four interface models between science communication and public policy were presented:-

- A Sequential Model (Funtowicz, 2006);
- A Participatory and Dynamic Model (Van der Hove and Sharman, 2006);
- A Governance Model (Hagendijk and Irwin, 2006); and
- An Interaction Model (Pulzl and Rametsteiner, 2009).

Each of the four interface models provided invaluable insights into how science-policy relationships progressed over time from simple linear models of explaining science to the public to complex, systemic, multi-directional and multi-linear models, which are more interactive in the way of a participative approach promoting science communication with and for everyone (Bora, 2005). The discussion on science-policy interfaces from chapter two resulted in two thematic segregations. The first thematic segregation combined the initial modern model, precautionary model, framing model and model of demarcation of Funtowicz (2006) with the informing policy model (Van der Hove and Sharman, 2006), the discretionary, corporatist and educational governance modes (Hagendijk and Irwin, 2006) and the transfer model of interaction (Pulzl and Rametsteiner, 2009). Collectively, these models purported explicit and linear boundaries between science and policy. The production of knowledge emanated as the responsibility of science as science speaks truth.

The second thematic segregation interconnected the models of extended participation (Funtowicz, 2006), mutual learning (Van der Hove and Sharman, 2006) and transaction (Pulzl and Rametsteiner, 2009) with the market, agonistic and deliberative governance modes of Hagendijk and Irwin (2006). These integrated models highlighted a fundamental shift in the status of science, as policy makers and practitioners co-produced multi-directional and experiential solutions to political and societal issues.

The progression of science policy interfaces, like the periodisation of science communication from chapter one, illustrates how science has mobilised from a product to a process orientation. The integration of informative, deliberative and participative processes of communication acknowledges the limitation of moving upstream in science communication (Wilsdon and Willis, 2004). Processes in science communication emphasise the diverse totality of actors, discourse, structures, and processes implicated in guiding and shaping social good and participative change for science communication (Stirling, 2008). Process orientations create an ideological balance between the science-policy interface models as listening, learning and exchanging become central to science-for-science, science-for-policy, science-for-society and science-for-action (Burgess and Clark, 2006; Van der Hove, 2007).

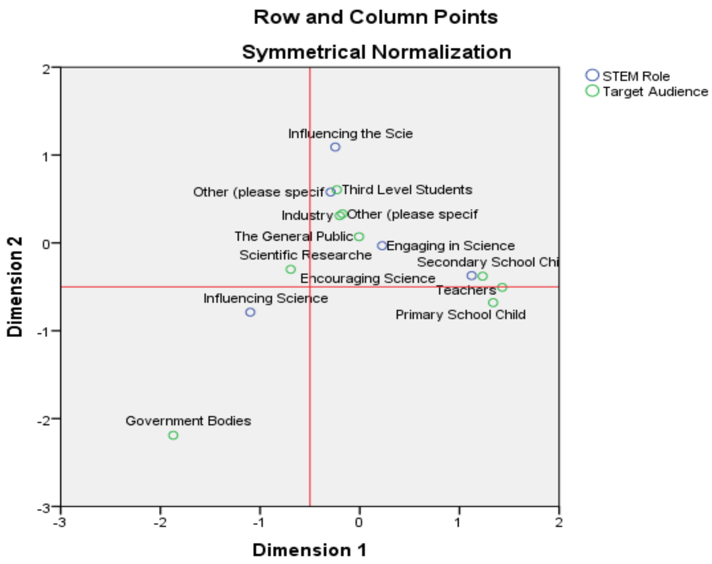
Secondary Objective 3: To determine how process activities differ, if at all, between science communicators with policy, practice and public orientations.

The roles of science communicators were examined in the first objective. The purpose of this third objective was to examine the work of science communicators in greater detail, assessing if target audience orientations determined the process activities of science communicators. Glicken (1999), Weigold (2001) and Lujan and Todt (2007) assigned specific orientations and target audiences to science communicators in the literature. These policy, practice and public orientations were measured in phase one of the study as a correspondence analysis determined the relative associations between STEM Role and STEM Areas and STEM Role and Target Audiences.

The correspondence analysis between STEM Role and STEM Area complements the literature as science communicators with policy level orientations were contrasted against science communicators who work with the public through science outreach. The hierarchical separation between policy makers and practitioners in science communication supports Bradshaw and Borcher's (2000) science-policy gap where the process of science is continually changing, so much so that science itself now precedes policy (Jones, 2010). This science-policy gap is further exasperated by the disconnected relationship between policy makers and practitioners in science communication practice. Another formative outcome of phase one surrounds the relative association between social science and science policy. The findings would suggest that those heavily involved in determining the future direction, scope and strategies of science derive from the social sciences as opposed to the pure sciences. The determination of policy maker backgrounds and qualifications is not discussed in the science communication literature, which could be attributable to the disconnected and hierarchical relationship between science policy and science communication practice.

The correspondence analysis between STEM Role and Target Audience also aligns with the thinking and views portrayed in the literature as government bodies are associated with science policy, as depicted in Figure 7.1.1.

Figure 7.1.1 Correspondence Analysis between STEM Role and Target Audience



Furthermore, governments and state bodies contrast substantially with the remaining audiences and roles as they appear in the lower left quadrant of the figure. The structural processes of science communicators with policy orientations converge with the correspondence findings and the literature, as policy and curriculum influencers are associated with hierarchical cultures in their organisations. Hierarchical cultures emphasise "order, uniformity, efficiency, certainty, stability and control, reflecting internally oriented and formalised values" (Moorman, 1995, p.322). Alternatively, science communicators with practice and public orientations reflected adhocracy and market cultures where efficiency and productivity as well as flexibility, adaptability and creativity are important facets to their process activities.

These findings reinforce the science policy literature where Bradshaw and Borchers (2000) critique science policy coordination for being indoctrinated by an authoritarian process of oversimplification. Correspondence analysis findings segregate government bodies at policy levels from outreach officers and educators at the practice and public level of science. Furthermore, science communicators at the policy level operate under a hierarchical culture which supports the assertions of McGuire and Olson (1996), Bradshaw and Borchers (2000) and Swyngedouw (2000) who recognise that governing structures operate under a regime of autocratic governance, creating oversimplified solutions to very complex policy and societal issues.

Secondary Objective 4: To analyse how value is created between science communicators.

Russell-Bennett, Previte and Zainuddin (2009) presented two approaches to value in social marketing; economic and experiential. Economic value focuses on the utility gained throughout the exchange process while experiential value approaches are interactive and relativistic experiences (Russell-Bennett, Previte and Zainuddin, 2009). Phase two of this study undertook a value network analysis which analysed how value was created between science communicators. Economic value was represented by the tangible and explicit deliverables exchanged between networking groups. Experiential values were present in each of the networking relationships in VNA, and were especially prominent in the non-contractual relationships, as science communicators valued the informal connections and relationships with partnering organisations.

Value is created in science communication through the process indicators of exchange, trust, commitment and reciprocity. The constructs of trust and commitment were not overtly expressed by the value network participants; instead the term reliability represented trust and goodwill represented commitment in the maps. Reliability and goodwill intrinsically underpin the guiding definitions of trust and commitment in this study as reliability reduces malicious behaviour and Kramer and Well's (2005) specifically outline goodwill in the commitment definition in Table 7.1.1.1.

Table 7.1.1.1 Trust and Commitment Definitions

Indicators	**Construct Definitions**
Trust	Trust is when both partners share similar values, when communication in their relationship is healthy and when their relationship history is not characterised by one partner maliciously taking advantage of the other (Hunt and Morgan, 1994, p.24)
Commitment	Commitment creates strong links through direct connections and ongoing relationships which are built through repeated, sequential forms of interaction and obeying the rules of reciprocity, which evolve into a common understanding of mutual commitments and trust in the goodwill of others (Kramer and Wells, 2005, p.430)

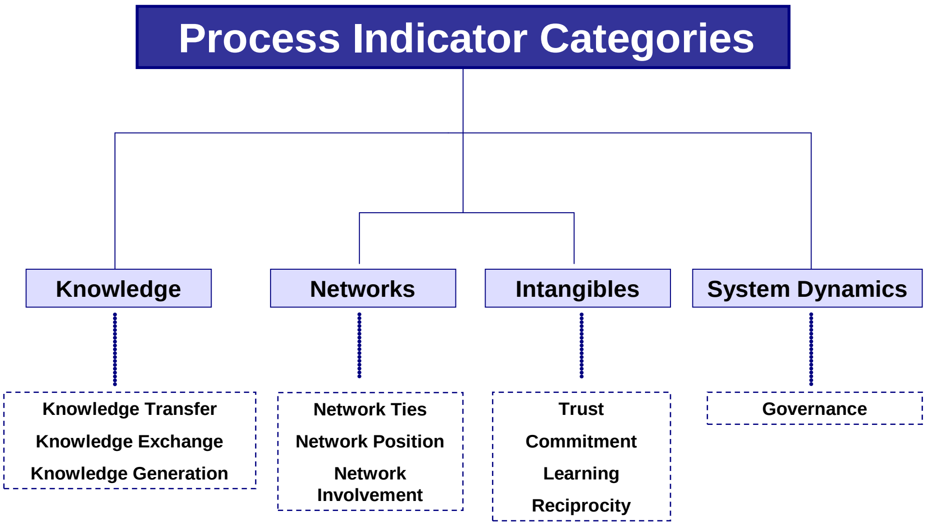
Roberts (2004, p.341) maintains that "the values are there, the strategies are there, the people are there. It is simply up to all of us to make it happen". Participant B from VNA concurs with this line of thinking as the science communicator stated that they "*just make things happen and get things done*". In VNA, value is co-created as science communicators emphasise conversations and engagement through collective participation. Collective participation in VNA supports Glicken's (1999) perspective in the literature where the integration and engagement of multiple audiences can make a difference to the process of science communication. To conclude, value co-creation is present in the value network maps as science communicators' sense, respond and learn from their exchanges and interactions with their networking partners (Desai, 2009). In addition, the co-creation of value in VNA strongly emphasises value-in-information which collectively integrates the knowledge, insights and perspectives of multiple stakeholders from multiple levels, creating holistic and experiential knowledge for science communication.

7.1.2 Primary Research Question

The primary research question of this study is how do process indicators contribute to the understanding of activities between science communicators in Ireland?

The primary research question of this study necessitated the development of process indicators. Through the application of Milbergs and Vonortas (2004) fourth generation process indicators, four process indicator categories for science communication were developed using social marketing and innovation theory in the literature review, as illustrated in Figure 7.1.2.

Figure 7.1.2 Process Indicators



Knowledge, intangibles, networks and system dynamics collectively emerged as the process indicators to measure the non-linear and multi-dimensional nature to science. Indicators measure the elements that stipulate and shape the processes in science communication, rather than the process itself (Dodgson and Hinze, 2000).

In a stepwise multiple regression in phase one of this study, the relationships between the process indicators were identified (See Table 7.1.2). The main finding from multiple regression is that there is an interlinked and interconnected relationship between the knowledge, networking and intangible process indicators of this study. The stepwise multiple regression analysis produced findings consistent with the literatures of science communication, social marketing and innovation theory.

Table 7.1.2 Summary of Significant Stepwise Regression Coefficients

Dependent Variable	Significant Regression Coefficients
Knowledge Generation	Knowledge Transfer; Network Involvement; Bridging Ties.
Knowledge Transfer	Trust; Knowledge Exchange; Strong Ties; Knowledge Generation; Network Involvement.
Knowledge Exchange	Trust; Network Involvement; Knowledge Transfer; Bridging Ties; Strong Ties.
Network Involvement	Knowledge Exchange; Reciprocity; Learning; Knowledge Transfer.
Bridging Ties	Commitment; Knowledge Exchange; Learning.
Strong Ties	Knowledge Exchange; Commitment; Trust; Network Involvement; Bridging Ties; Knowledge Transfer.
Trust	Knowledge Exchange; Knowledge Transfer; Commitment.
Commitment	Strong Ties; Bridging Ties; Trust; Learning.
Learning	Commitment; Bridging Ties.
Reciprocity	Network Involvement; Learning.

Knowledge in science communication, albeit its generation, transfer or exchange is best predicted by network involvement, network ties and trust. The most notable contribution of the knowledge indicators concerns knowledge transfer which was defined by Jacobsen (2007) as a logical one-way flow of information. Social marketing and innovation theory suggest that knowledge transfer is a unilateral process subsumed with self-interest (Buchanan, Reddy and Hossain, 1994). However, trust was identified as a predictor of knowledge transfer, suggesting that the process of moving knowledge requires mutual benefits and non-malicious behaviour (Hunt and Morgan, 1994), conflicting with the theoretical perspectives of Buchanan, Reddy and Hossain (1994).

In relation to network ties, strong ties in comparison to bridging ties produced more predictor variables. This finding co-aligns with the supporting literature on network ties as respondents commit to their long-term connections and relationships within the STEM industry.

The intangibles of trust and commitment supported the thinking of Hunt and Morgan (1994) in the literature as both were viewed as antecedents to the formation of relationships. Trust became central to the transfer and exchange of knowledge, whereas commitment and sequential forms of interaction (Kramer and Wells, 2005) were important predictors for network ties.

The process indicators in phase one produced a snap shot in time, whereas phase two allowed the researcher to gain more in-depth insights and understanding into the relative importance of the process indicators through value network maps. Value network maps addressed the process indicators through the lens of a long-term orientation. Arising from VNA, two findings emerged which were not conceptualised in the literature or evident in the online survey findings. The first finding relates to reciprocity and the second finding relates to trust.

Science communicators contrast reciprocity in short-term relationships against reciprocity in long-term relationships. In practice, science communicators conflict with the views of Buchanan, Reddy and Hossain (1994), who maintain that there is little consensus towards mutuality in exchange relationships, as contributors are motivated by self-interested goals and manipulation. Science communicators, even in pursuit of self-interested motivations will always "*return the favour, if they can at a later stage*" (VNA: Participant B). This willingness between science communicators critically underpins trust and contributes to the formation of long term relationships between science communicators. In practice, reciprocity contributes to the nurturing of intangible relationships in the value network system of science.

Even relationships perceived as having medium levels of value were identified as reciprocal because these networking partners "*are so busy, they don't have the time to give a lot back*" (VNA: Participant E). Science communicators appreciate the intensity of the science communication activities of their networking partners, intercepting that the quid pro quo element of reciprocity occurs throughout the course of a long-term relationship in VNA, as opposed to occurring instantaneously. This finding extends both the concept of exchange and reciprocity in the three streams of literature.

The second finding surrounds trust in science communication. Science communication theorists attribute a crisis of trust to the public and to science (Sturgis and Allum, 2004). However, trust did not emerge as an issue for science communicators because participants noted, if trust is not apparent in the relationship, then the relationship ceases to exist. Furthermore, trust is about "*competency and, professionalism and technical ability*" (VNA: Participant F), and needs to be managed to ensure partners behave appropriately and respectively with one another. Furthermore, VNA identified reliability as an important antecedent to trustworthy relationships. As the reliability of a science communicator gains momentum and acknowledgment, it results in repeated network exchanges and progresses into a trustworthy relationship over time. Outcomes of trust in science communication include referrals, recommendations, prestige by association and credibility which facilitate subsequent "*conversational crossover networks*" (VNA: Participant B) between science communicators.

In addition to the consequential findings of the primary research question, the process indicators have also created several theoretical, methodological, policy and managerial implications as detailed below.

7.1.2.1 Theoretical Implication of Process Indicators

The theoretical implication of this study is the development of process indicators from the integration of science communication with social marketing and innovation theory. Milbergs and Vonortas (2004); Stone et al. (2008) and Rose et al. (2009) presented a fourth generation of process indicators in the literature, however these indicators had not been empirically tested or measured since their inception from the year 2000 onwards.

This study through an interdisciplinary approach to science communication operationalised four process indicator categories; knowledge, intangibles, networks and system dynamics and through deductive reasoning, produced eleven construct definitions and eleven measurement scales for each of the process indicators. The measurement of these eleven process indicators not only advances the area of science communication but the process indicators also contribute to the enhanced understanding of a total market approach in social marketing and open system approaches in innovation.

More specifically, the interdisciplinary integration of science communication with social marketing extends the social marketing literature as all too often the field is reluctant to move beyond individual-based behavioural change (Lefebvre, 2000). The incorporation of Social Ecology Theory (Bronfenbrenner, 1979) to the area of science communication in this study is a new and contemporised application of social marketing which moves social marketing beyond environmental and health applications to the upstream investigation of science policy and science communication.

Theoretically, this research has implications for the social marketing literature as it advances the concept of a total market approach within social marketing. This study formally integrates Gronroos' (2004) relationship marketing concepts of communication and dialogue, interaction, value and value co-creation with a total market approach to social marketing, extending Marques (2008); Russell-Bennett, Previte and Zainuddin (2009) and Marques and Domegan's (2011) understanding of effective participation and public empowerment within social marketing.

Another theoretical implication for social marketing is the amalgamation of the trust, commitment, learning and reciprocity indicators under the heading '*Intangibles*' in social marketing. Intangibles are a term synonymous with the services marketing literature yet the term has not been fully translated into the discipline of social marketing. The positioning of the term within social marketing emphasises the applicability of service marketing constructs to the discipline of social marketing, where at present the boundaries between the two disciplines are beginning to permeate through the work of Zainuddin, Russell-Bennett, and Previte in 2007 and

Russell-Bennett, Previte and Zainuddin in 2009. This study also advances Hunt and Morgan's (1994) thinking on trust, as the authors advocate trust as an antecedent to relationship formation. The findings from this research identify reliability as the antecedent to trust which poses new research implications for social marketing.

Furthermore, the development of a process indicator framework produces significant implications for social marketing. Although the process indicator framework has been applied to the area of science communication, it is applicable and beneficial to the understanding of marketing systems, macro management, stakeholder analyses, value networks, and collaborative partnerships across health, the environment and conservational issues within social marketing.

7.1.2.2 Methodological Implication of Process Indicators

Methodologically, the process indicators contributed to the examination of participation at the practice level of science communication. The practice level of science represents an under-researched and under-explored priority group of science. The measurement of the process indicators advanced the understanding of the practice level by examining the knowledge, networking, relational and structural processes of science communicators. Furthermore, this study graphically captures the networking of networks approach in science communication, by visualising how science communicators exchange and co-create value at the practice level of science.

Traditionally, indicators of science and technology measure macro level input-output activity. The development of process indicators in this study answers the call perpetuated by Gault (2007) and Blankley (2009) for indicators that produce meso level and micro level data. In this study, meso level data arises from the understanding of process activities between science practitioners, while micro level data is produced from the stratifications of the policy, practice and public level orientations of science communicators.

The analysis of process indicators through VNA in this study extends the traditional use and application of the VNA methodology, where networks of organisations are measured as opposed to systems of organisations. Furthermore, the examination of networks of organisations extends the concept of intangible deliverables in VNA to incorporate explicit and implicit deliverables. Explicit deliverables for this study have been defined as anything you can physically feel, see or touch whereas implicit intangibles include “those little extras people do that help keep things running smoothly and build relationships (Allee, 2008, p.11) such as goodwill and expertise.

Methodologically, VNA has implications for the measurement of value co-creation within social marketing, as co-creation emphasises the bi-directional and multi-directional interactions that occur between groups (Zainuddin, Russell-Bennett and Previte, 2007). Social marketing has yet to yield a network methodology that goes beyond the traditional analysis of identifying ‘*who*’ is involved in a network. This study not only captures ‘*who*’ is involved in a network, but also ‘*what*’ is exchanged in a network and ‘*how*’ those explicit and implicit values are exchanged, visualising how bi-directional and multi-directional value co-creation occurs within social marketing.

7.1.2.3 Policy Implication of Process Indicators

The development and measurement of process indicators in this study provides an alternative model of measurement to the traditional and often restrictive input-output models in science (Godin, 2001). This study contributes to science policy and indicator measurement frameworks as process indicators measure the activity of science communicators at the meso and micro levels of science, creating an alternative measurement framework to the macro input-output statistics and the productivity frameworks of individual micro level organisations.

The VNA of process indicators captures the properties of the individual organisations in science communication as well as capturing a big picture model of the interactions, connections and linkages in the system. VNA effectively illustrates the processes by which science communicators form networks, exchange knowledge, build trust and enhance credibility. In this study, the mapping of value networks goes beyond ‘who’ is involved in science communication and effectively captures ‘what’ is exchanged in science communication and ‘how’ exchanges take place. This study illustrates how VNA is a valuable analytical technique for policy as it provides powerful insights into the health and sustainability of a policy system, whilst also providing a graphical representation of value networks and process indicator exchanges in science communication.

7.1.2.4 Managerial Implication of Process Indicators

Process indicators from this study enable managers to gain a deeper understanding of how knowledge is generated within the boundaries of the firm. Innovation literature recognises that knowledge takes two forms; explicit and tacit knowledge (Seufert, vonKrogh and Bach, 1999; Choi and Lee, 2002; Katsamakas, 2007). The measurement of knowledge in this study provides evidence to managers on whether knowledge is generated within a firm through documents, manuals, and databases, or whether the knowledge is intrinsic to an individual. This information is valuable to a manager as it highlights the need to create or maintain the systematic storage and codification of organisational documentation and training manuals. Furthermore, the process indicators in this study also provide managers with information on knowledge transfer and exchange as well as network composition.

In this study, VNA provides powerful illustrative evidence of the process activities which occur between an organisation and its networking partners. This type of information is important to management, as it comprehensively illustrates the connections, communicational linkages and exchanges of an organisation. VNA also identifies whether the process exchanges are unidirectional, bi-directional or multi-directional. Value networks demonstrate to managers the best way to create, extend and leverage value with other organisations.

VNA also provides a visualisation of value to management. The visual maps produced for participants in this study are currently being incorporated with communication strategies, illustrating the process activities of an organisation and the movement of knowledge between networks of organisations to management and head offices.

From a managerial perspective, the use of VNA in conjunction with social marketing makes management more aware of the behaviours of their networking partners, acknowledging that behaviours do not occur in a vacuum. Management from the participating organisations are now more conscious of the intangible constructs of trust, commitment and reciprocity throughout their daily routines and practices. In particular, management are more sensitive to the reciprocal behaviour of their networking partners in terms of goodwill, reliability, credibility and trustworthiness, which influences how managers make decisions over those whom the organisation connects with, or disconnects from, for the sharing and exchange of expertise and knowledge in the future.

Throughout the course of this study, eleven process indicators were developed for science communication using social marketing and innovation theory. As the study progressed through the three sequential stages of the literature review, the online survey and VNA, the researcher became aware of areas which could benefit from future research. These specific areas for future research are outlined in the final section of this thesis.

7.2 Recommendations for Future Research

The areas for future research fall into four broad categories; theoretical, methodological, policy and managerial recommendations.

7.2.1 Theoretical Recommendations

The value network approach employed in this study suggests that further research is needed into the conceptualisation of conversational crossover networks. Innovation identifies the coordination of organic and strategic networks but lacks a theoretical conceptualisation of referral networks and conversational crossover networks from practice. The concept of conversational crossover networks is also absent from the science communication literature and further research into this construct could assess its validity in participation and the science-in-society paradigm.

An outcome of the qualitative phase emphasised the construct of reciprocity and its differential meanings in short-term and long-term relationships. Further research could specifically examine the interconnections between reciprocity and exchange in science communication relationships. A broader conceptualisation of reciprocity in the literature could provide an enhanced understanding of the types and meaning of exchange in social marketing, science communication and innovation. In addition, trust is treated by Hunt and Morgan (1994) as an antecedent to relationship formation. The findings from this research identified reliability as the antecedent to trust. Science communicators posit that trust needs to be managed. The management of trust is another area which lacks theoretical conceptualisation in science communication, social marketing and innovation.

7.2.2 Methodological Recommendations

This research incorporated a cross-sectional design where the online survey and VNA addressed science communication as a snapshot in time. The online survey identified the underlying factors and predictors of the process indicators while the value network maps explored the process indicators in greater detail. The process indicators for science communication can be further validated by testing them as part of a longitudinal study. A longitudinal research design could measure the knowledge, networking, relational and structural processes of science communicators over time. This type of research design would benefit the value network maps as science communicators could easily identify sustainable relationships and network partnerships which have transcended from strong to bridging or weak ties. Furthermore, a longitudinal approach to VNA would assess the consistency of deliverables and reciprocity in science communication.

The application of VNA for the first time in this study needed to assess the presence of networks and network relationships in science communication. This study highlighted that each of the seven VNA participants was highly connected, both contractually and non-contractually. The visual evidence provides an opportunity for further research to employ the traditional application of VNA in science communication, as a specific deliverable, issue or problem highlighted by a participant could be isolated and examined from the perspective of all network groups in the value network map.

7.2.3 Policy Recommendations

The VNA component to this research lacked a value network map from science communicators who govern science and its coordination in Ireland. Future research in science communication could validate the theoretical assumptions of policy level science, through the presentation of a policy value network map. A policy map could provide further empirical evidence surrounding the structural processes of governing bodies, confirming or attesting the hierarchical and authoritarian behaviour of upstream, macro environmental science communicators.

Finally, the aim of this research was not to generalise the results to science communication and populations outside of the ROI. However, the process indicators which were developed for science communication in this study can also be applied to other sectors and governance issues such as health, the environment, education and religion.

7.2.4 Managerial Recommendations

This research measured process indicators across the general sector of science communication. This generic approach was employed due to the lack of previous empirical evidence relating to process indicators and participation in science communication. There is now an opportunity for further research to delve deeper into a specific area of science communication practice, such as policy makers, outreach officers, educators or scientists. The assessment of process activities between public, private and non-profit organisations provides another avenue for further research, to determine how process activities differ, if at all, between the three sectors.

List of Appendices

Appendices can be found on the enclosed CD

List of References

Aaker, D., Kumar, V, Day, G. and Leone, R. (2011) *Marketing Research, 10th Edition*, John Wiley and Sons (Asia) Pte Ltd.

Achrol, R. (1997) Changes in the theory of interorganisational relations in marketing: toward a network paradigm. *Journal of the Academy of Marketing Science*, 25(1), 56-71.

Adeoti, J. and Olubamiwa, O. (2009) Towards an innovation system in the traditional sector: the case of the Nigerian cocoa industry. *Science and Public Policy*, 36(1), 15-31.

Allee, V. (2008) Value network analysis and value conversion of tangible and intangible assets. *Journal of Intellectual Capital*, 9(1), 5-24.

Allee, V. (2009) Value-creating networks: organisational issues and challenges. *The Learning Organisation*, 16(6), 427-442.

Allee, V. (2011) *Value Networks and the True Nature of Collaboration*. Available at: www.valuenetworksandcollaboration.com [Accessed 03/02/2011].

Allum, N., Sturgis, P., Tabourazi, D. and Brunton-Smith, I. (2008) Science knowledge and attitudes across cultures: a meta – analysis. *Public Understanding of Science*, 17(1), 35-54.

Anderson, W., Challagalla, G. and McFarland, R. (1999) Anatomy of exchange. *Journal of Marketing Theory and Practice*, 7(4), 8-19.

Andreasen, A. (2006) *Social Marketing in the Twenty-First Century*. London, UK, Sage Publications Inc.

Bagozzi, R. (1975) Marketing as exchange. *Journal of Marketing*, 39(4), 32-39.

Ballantyne, D. (2004) Dialogue and its role in the development of relationship specific knowledge. *Journal of Business and Industrial Marketing*, 19(2), 114-123.

Ballantyne, D. and Varey, R. (2006) Introducing a dialogical orientation to the service-dominant logic of marketing. In Lusch, R.F. and Vargo, S.L. (Eds) *The Service Dominant Logic of Marketing: Dialog, Debate and Directions*, New York, M.E. Sharpe, Inc., 224-235.

Baranowski, T., Cullen, K., Nicklas, T., Thompson, D. and Baranowski, J. (2003) Are current health behavioural change models helpful in guiding prevention of weight gain efforts? *Obesity Research*, 11, 23-43.

Barney, J. (2001) Is the resource-based view a useful perspective for strategic management research? Yes. *Academy of Management Review*, 25(1), 41-56.

Barney, J., Wright, M. and Ketchen, D. (2001) The resource-based view of the firm: the years after 1991. *Journal of Management*, 27(6), 625-641.

Bartholomew, D., Steele, F., Moustaki, I. and Galbraith, J. (2008) *Analysis of Multivariate Social Science Data, 2nd Edition*, Florida, Taylor and Francis Group, LLC.

Batt, P. and Purchase, S. (2004) Managing collaboration within networks and relationships. *Industrial Marketing Management*, 33, 169-174.

Bauer, M. (2009) The evolution of public understanding of science discourse and comparative evidence. *Science, Technology and Society*, 14(2), 221-240.

Bauer, M., Allum, N. and Miller, S. (2007) What can we learn from 25 years of PUS survey research? Liberating and expanding the agenda. *Public Understanding of Science*, 16(1), 79-95.

Bearden, W. and Netemeyer, R. (1999) *Handbook of Marketing Scales: Multi-Item Measures for Marketing and Consumer Behaviour Research, 2nd Edition*, Thousand Oaks, California, Sage Publications Inc.

Bell, L. (2008) Engaging the public in technology policy: a new role for science museums. *Science Communication*, 29(3), 386-398.

Bellavista, J. and Sanz, L. (2009) Science and technology parks: habitats of innovation. *Science and Public Policy*, 36(7), 499-510.

Benneworth, P. (2009) *The Challenges for 21st Century Science: A Review of the Evidence Base Surrounding the Value of Public Engagement by Scientists*. Centre for Higher Education Policy Studies, UK.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S. and Rickne, A. (2008) Analysing the functional dynamics of technological innovation systems: a scheme of analysis. *Research Policy*, 37, 407-429.

Besley, J. and Tanner, A. (2011) What science communication scholars think about training scientists to communicate? Science Communication, 33(2), 239-263.

Biesta, G. (2010) Pragmatism and the philosophical foundations of mixed methods research. In Tashakkori, A. and Teddlie, C. (Eds*) Sage Handbook of Mixed Methods in Social and Behavioural Research*, Thousand Oaks, California, Sage Publications Inc, 95-118.

Binney, W., Hall, J. and Shaw, M. (2003) A further development in social marketing. *Marketing Theory*, 3(3), 387-403.

Blankley, W. (2009) Key Innovation and Knowledge Indicators for South Africa. Available at: http://www.naci.org.za/pdfs/workshops [Accessed 05/02/2010].

Bodas-Freitas, I. (2007) New instruments in innovation policy: the case of the Department of Trade in the UK. *Science and Public Policy*, 34(9), 644-656.

Bokeno, R. and Gantt, V. (2000) Dialogic mentoring. *Management Communication Quarterly*, 14(2), 237-270.

Bond, E.U., Houston, M. and Tang, Y. (2008) Establishing a high-technology knowledge transfer network: the practical and symbolic roles of identification. *Industrial Marketing Management*, 37, 641-652.

Bora, A. (2005) 'Science, Society and the Lisbon strategy'. *Science in Society – Forum 2005*, Brussels, March 9th – 11th.

Borchelt, R. (2001) Communicating the future: report of the research roadmap panel for public communication of science and technology in the twenty-first century. *Science Communication*, 23(2), 194-211.

Borgatti, S. and Foster, P. (2003) The network paradigm in organisational research: a review and typology. *Journal of Management*, 29(6), 991-1013.

Borzel, J. and Heard-Laureote, K. (2009) Networks in EU multi-level governance: concepts and contributions. *Journal of Public Policy*, 29(2), 135-152.

Bradshaw, G. and Borchers, J. (2010) Uncertainty as information: narrowing the science-policy gap. *Ecology and Society*, 4(1), 1-10.

Brafman, O. and Beckstrom, R. (2006) *The Starfish and the Spider – The Unstoppable Power of Leaderless Organisations*. Dublin, Ireland, Penguin Group.

Bragesjo, F., Elzinga, A. and Kasperowski, D. (2012) Continuity or discontinuity? Science governance in the pre-history of the 1977 law of higher education and research in Sweden. *Minerva*, 50, 65-96.

Braun, D. (2008) Organising the political coordination of knowledge and innovation policies. *Science and Public Policy*, 35(4), 227-239.

Braun, K. and Schultz, S. (2010) "...a certain amount of engineering involved": constructing the public in participatory governance arrangement. *Public Understanding of Science*, 19(4), 403-419.

Bronfenbrenner, U. (1977) Lewinian space and ecological substance. *Journal of Social Issues*, 33(4), 199-212.

Bronfenbrenner, U. (1978) The social role of the child in ecological perspective. *Journal of Sociology*, 7(1), 4-20.

Bronfenbrenner, U. (1979) Toward an experimental ecology of human development. *American Psychologist*, 32, 513-531.

Brossard, D. and Shanahan, J. (2006) Do they know what they read? Building a scientific literacy measurement instrument based on science media coverage. *Science Communication*, 28(1), 47-63.

Bryman, A. and Bell, E. (2007) *Business Research Methods, 2nd Edition*. New York, Oxford University Press Inc.

Bucchi, M. (2008) Of deficits, deviations and dialogues – theories of public communication of science. In Bucchi, M. and Trench, B. (Eds) *Handbook of Public Communication of Science and Technology*. Madison Avenue, New York, Routledge Taylor and Francis Group, 57-76.

Buchanan, D., Reddy, S. Ad Hossain, H. (1994) Social marketing: a critical appraisal. Health Promotion International, 9(1), 49-57.

Burgess, J. and Clark, J. (2006) Evaluating public and stakeholder engagement strategies in environmental governance. In Guimaraes-Pereira, A., Guedes-Vaz, S. and Tognetti, S. (Eds) *Interfaces between Science and Society*. Sheffield, United Kingdom, Greenleaf Publishing Ltd, 225-252.

Burningham, K., Barnett, J., Carr, A., Clift, R. and Wehrmeyer, W. (2007) Industrial constructions of publics and public knowledge: a qualitative investigation of practice in the UK chemicals industry. *Public Understanding of Science*, 16(1), 23-43.

Burns, R. and Burns, R. (2008) *Business Research Methods and Statistics Using SPSS*, Thousand Oaks, California, Sage Publications Inc.

Burns, T., O'Connor, D. and Stocklmayer, S. (2003) Science communication: a contemporary definition. *Public Understanding of Science*, 12(2), 183-202.

Capaldo, A. (2007) Network structure and innovation: the leveraging of a dual network as a distinctive relational capability. *Strategic Management Journal*, 28, 585-608.

Casey, D. and Brugha, C. (2005) Questioning cultural orthodoxy: policy implications for Ireland as an innovative knowledge-based economy. *E:CO*, 7(1), 2-10.

Castro, F., Kellison, J., Boyd, S. and Kopak, A. (2010) A methodology fro conducting integrative mixed methods research and data. *Journal of Mixed Methods Research*, 4(4), 342-360.

Chakravorti, B. (2004) The new rules for bringing innovations to market. *Harvard Business Review*, 82(3), 58-67.

Chapman, J. (2004) *System Failure – Why Governments Must Learn to Think Differently*, 2nd Edition. London, UK, Demos.

Chesbrough, H. (2011) Bringing open innovation to services. *MIT Sloan Management Review*, 52(2), 85-90.

Chesbrough, H. and Appleyard, M. (2007) Open innovation and strategy. *California Management Review*, 50(1), 57-76.

Chilvers, J, (2008) Deliberating competence: theoretical and practitioner perspectives on effective participatory appraisal practice. *Science, Technology & Human Values*, 33(2), 155-185.

Chilvers, J. (2009) Deliberative and participatory approaches in environmental geography. In Castree, N., Demeritt, D., Liverman, D. and Rhoads, B. (Eds) *A Companion to*

Environmental Geography. Sussex, United Kingdom, Blackwell Publishing Ltd, 400-417.

Chiva, R., Alegre, J. and Lapiedra, R. (2007) Measuring organisational learning capability among the workforce. *International Journal of Manpower*, 28(3/4), 224-242.

Cho, H. and Pucik, V. (2005) Relationship between innovativeness, quality, growth, profitability and market value. *Strategic Management Journal*, 26, 555-575.

Choi, B. and Lee, H. (2002) Knowledge management strategy and its link to knowledge creation process. *Expert Systems with Applications*, 23, 173-187.

Chung, S., Singh, H. and Lee, K. (2000) Complementarity, status similarity and social capital as drivers of alliance formation. *Strategic Management Journal*, 21(1), 1-22.

Churchill, G. (1979) A paradigm for developing better measures of marketing constructs. *Journal of Marketing Research*, 16, 64-73.

City of Onkaparingo (2000) *Monitoring Outcomes, Achieving Goals: A Practical Guide for Using Community Indicators to Monitor the Strategic Directions of a Local Government Area or Region*. Department of Strategy and Policy, City of Onkaparingo, SA.

Cohen, W. and Levinthal, D. (1990) Absorptive capacity: a new perspective on learning and innovation. *Administrative Science Quarterly*, 35, 128-152.

Collins, K., Onwuegbuzie, A. and Jiao, Q. (2006) Prevalence of a mixed-methods sampling designs in social science research. *Evaluation and Research in Education*, 19(2), 83-101.

Conroy, C. (2007) Innovation is every company's business. *MII News*, October 2007.

Cook, J. and Wall, T. (1980) New work attitude measures of trust, organisational commitment and personal need non-fulfilment. *Journal of Occupational Psychology*, 53, 39-52.

Corbin, J. and Morse, J. (2003) The unstructured interactive interview: issues of reciprocity and risks when dealing with sensitive topics. *Qualitative Inquiry*, 9(3), 335-354.

Costanza, R., Wainger, L., Folke, C. and Maler, K. (1993) Modelling complex ecological economic systems. *Bioscience*, 43(8), 545-555.

Costello, A. and Osborne, J. (2005) Best practices in exploratory factor analysis: four recommendations for getting the most from your analysis. *Practical Assessment, Research and Evaluation*, 10(7), 1-9.

Cotic-Svetina, A., Jaklic, M. and Prodan, I, (2008) Does collective learning in clusters contribute to innovation. *Science and Public Policy*, 35(5), 335-345.

Council on Competitiveness (2005) *Innovate America*. National Innovation Initiative Summit and Report, United States of America.

Cova, B., Prevot, F. and Spencer, R. (2010) Navigating between dyads and networks. *Industrial Marketing Management*, 39, 879-886.

Cowan, R., Jonard, N. and Zimmermann, J. (2007) Bilateral collaboration and the emergence of innovation networks. *Management Science*, 53(7), 1051-1067.

Coyle, D. and Beth-Childs, M. (2008) *Wider Conditions for Innovation*. NESTA Innovation Index Working Paper, London, UK.

Creswell, J. (2003) *Research Design, Qualitative, Quantitative, and Mixed Methods Approaches, 2nd Edition*, Thousand Oaks, California, Sage Publications Inc

Creswell, J. (2009) *Research Design, Qualitative, Quantitative, and Mixed Methods Approaches, 3rd Edition*, Thousand Oaks, California, Sage Publications Inc.

Creswell, J., Plano-Clark, V., Gutmann, M. and Hanson, W. (2003) Advanced mixed methods research designs, In Plano-Clark, V. and Creswell, J. (Eds; 2008) *The Mixed Methods Reader*, Thousand Oaks, California, Sage Publications Inc, 161-196.

Crutchfield, L. and McLeod-Grant, H. (2008) *Forces for Good – The Six Practices of High-Impact Nonprofits*. San Francisco, John Wiley & Sons Inc.

Cullen, J., Sullivan, F. and Junge, K. (2007) *Evaluating Science and Society Initiatives: A Framework for Evaluation*. The Tavistock Report.

Czaja, R. (1998) Questionnaire pretesting comes of age. *Marketing Bulletin*, 9(5), 52-66.

Dann, S. (2008) Adaptation and adoption of the American marketing association (2007) definition for social marketing. *Social Marketing Quarterly*, 14(2), 92-100.

Darnton, A. (2008) *GSR Behaviour Change Knowledge Review: Overview of Behaviour Change Models and their Uses - Briefing Note for Policy Makers*. Available at: www.gsr.gov.uk [Accessed 29/09/2009].

Davies, S. (2008) Constructing communication: talking to scientists about talking to the public. *Science Communication*, 29(4), 413-434.

Davies, S. (2009) Doing dialogue: Genre and flexibility in public engagement with science. *Science as Culture*, 18(4), 397-416.

Davies, S., McCallie, E., Simonsson, E., Lehr, J. and Duensing, S. (2009) Discussing dialogue: perspectives on the value of science dialogue events that do not inform policy. *Public Understanding of Science*, 18(3), 338-353.

Davison, K., McCauley, V., Domegan, C. and McClune, W. (2008) *A Review of Science Outreach Strategies North and South*. Armagh, Northern Ireland, Centre for Cross Border Studies.

Delgado, A. (2010) Activist truth: the diffusion of green expertise in a Brazilian landscape. *Public Understanding of Science*, 19(5), 562-577.

Delgado, A., Kjolberg, K.L. and Wickson, F. (2011) Public engagement coming of age: from theory to practice in STS encounters with nanotechnology. *Public Understanding of Science*, 20(6), 826-845.

Denscombe, M. (2008) Communities of practice: a research paradigm for the mixed methods approach. *Journal of Mixed Methods Research*, 2(3), 270-283.

Desai, D. (2009) Role of relationship marketing and value co-creation in social marketing. *Social Marketing Quarterly*, 15(4), 112-125.

Deshpande, R., Farley, J. and Webster, F. (1993) Corporate culture, customer orientation and innovativeness in Japanese firms: a quadrad analysis. *Journal of Marketing*, 57, 23-27.

Deshpande, S., Rothschild, M. and Brooks, R. (2004) New product development in social marketing. *Social Marketing Quarterly*, 10(3), 39-49.

Dhanaraj, C. and Parkhe, A. (2006) Orchestrating innovation networks. *Academy of Management Review*, 31(3), 659-669.

Dholakia, R. (1984) A macromarketing perspective on social marketing: the case of family planning in India. *Journal of Macromarketing*, 4(1), 53-61.

DiCicco-Bloom, B. and Crabtree, B. (2006) The qualitative research interview. *Medical Education*, 40, 314-321.

Dijkstra, A. and Gutteling, J. (2012) Communicative aspects of the public-science relationship explored: results of focus group discussions about biotechnology and genomics. *Science Communication*, 34(3), 363-391.

Dillman, D. (2007) *Mail and Internet Surveys: The Tailored Design Method, 2nd Edition*. New Jersey, John Wiley & Sons, Inc.

Dodgson, M. and Hinze, S. (2000) Measuring innovation - indicators used to measure the innovation process: defects and possible remedies. *Research Evaluation*, 8(2), 101-114.

Doey, L. and Kurta, J. (2011) Correspondence analysis applied to psychological research. *Tutorials in Quantitative Methods for Psychology*, 7(1), 5-14.

Domegan, C. (2008) Social marketing: implications for contemporary marketing practices classification scheme. Journal of Business and Industrial Marketing, 23(2), 135-141.

Domegan, C. and Fleming, D. (2007) *Marketing Research in Ireland: Theory and Practice, 3rd Edition*, Dublin, Gill and Macmillan Ltd.

Dornan, C. (1990) Some problems of conceptualising the issue of science and the media. *Critical Studies in Mass Communication*, 7, 48-71.

Dresler-Hawke, E. and Veer, E. (2006) Making healthy eating messages more effective: combining integrated marketing communication with the behaviour ecological model. *International Journal of Consumer Studies*, 30(4), 318-326.

Dussauge, P., Garrett, B. and Mitchell, W. (2000) Learning from competing partners: outcomes and durations of scale and link alliances in Europe, North America and Asia. *Strategic Management Journal*, 21(2), 99-126.

Dyer, J. and Hatch, N. (2006) Relation-specific capabilities and barriers to knowledge transfers: creating advantage through network relationships. *Strategic Management Journal*, 27, 701-719.

Easton, G. and Araujo, L. (1994) Market exchange, social structures and time. *European Journal of Marketing*, 28(3), 72-84.

Ertl, H., Bordt, M., Earl, L., Lacroix, A., Lonmo, C., McNiven, C., Schaan, S., Uhrbach, M., van Tol, B. and Veenhof, B. (2006) 'Towards understanding impacts of science, technology and innovation activities'. *Blue Sky II Forum*, Ottawa, Canada, September 25th – 27th.

European Commission (2007) *Taking European Knowledge Society Seriously*. Report of the Expert Group on Science and Governance to the Science, Economy and Society Directorate. European Directorate General for Research.

European Commission (2009) *Challenging Futures of Science in Society: Emerging Trends and Cutting-Edge Issues – The Masis Report*. European Directorate General for Research.

Falchetti, E., Caravita, S. and Sperduti, A. (2007) What do laypersons want to know from scientists? An analysis of a dialogue between scientists and laypersons on the website Scienzaonline. *Public Understanding of Science*, 16(4), 489-506.

Falk, J., Storsdieck, M. and Dierking, L. (2007) Investigating public science interest and understanding: evidence for the importance of free-choice learning. *Public Understanding of Science*, 16(4), 455-469.

Fernandez-Carro, R. (2007) A principal-agent model of public research with a retrospective payoff rule. *Science and Public Policy*, 34(5), 317-328.

Firestone, W. (1987) Meaning in method: the rhetoric of quantitative and qualitative research. *Educational Researcher*, 16(7), 16-21.

Fleming, J. (2009) Talking with barmaids: the importance of science communication in today's changing world. *The International Journal of Science in Society*, 1(1), 31-38.

Forfas (2011) *Strategy for Science, Technology and Innovation Indicators - December 2011*, Dublin, Ireland.

Forfas (2012) *The Science Budget 2010-2011: State Expenditure on Science and Technology and Research and Development.* Dublin, Ireland.

Freeman, C. and Soete, L (2009) Developing science, technology and innovation indicators: what we can learn from the past. *Research Policy*, 38, 583-589.

French, J. (2009) The nature, development and contribution of social marketing to public health practice since 2004 in England. *Perspectives in Public Health*, 129(6), 262-267.

French, J. and Blair-Stevens, C. (2010a) Key concepts and principles of social marketing. In French, J., Blair-Stevens, C., McVey, D. and Merritt, R. (Eds) Social Marketing and Public Health: Theory and Practice, United States, Oxford University Press Inc., 29-44.

French, J. and Blair-Stevens, C. (2010b) Using social marketing to develop policy, strategy and operational synergy. In French, J., Blair-Stevens, C., McVey, D. and Merritt, R. (Eds) Social Marketing and Public Health: Theory and Practice, United States, Oxford University Press Inc., 67-80.

French, J., Blair-Stevens, C., McVey, D. and Merritt, R. (2010) *Social Marketing and Public Health – Theory and Practic*e. Oxford, UK, Oxford University Press.

Funtowicz, S. (2006) Why knowledge assessment? In Pereira, A., Vaz, S. and Tognetti, S. (Eds) *Interfaces Between Science and Society*. Sheffield, United Kingdom, Greenleaf Publishing Ltd, 138-145.

Gault, F. (2007) Science, technology and innovation indicators: the context of change. In *Science, Technology and Innovation Indicators in a Changing World – Responding to Policy Needs*. Organisation for Economic Co-operation and Development Statistics Publications, Paris, France, 9-24.

Gerbing, D. and Anderson, J. (1988) An updated paradigm fro scale development incorporating unidimensionality and its assessment. *Journal of Marketing Research*, 25(2), 186-192.

Glasgow, R. and Emmons, K. (2007) How can we increase translation of research into practice? Types of evidence needed. *Annual Review of Public Health*, 28, 413-433.

Glenane-Antoniadis, A., Whitwell, G., Bell, S. and Menguc, B. (2003) Extending the vision of social marketing through social capital theory: marketing in the context of intricate exchange and market failure. *Marketing Theory*, 3(3), 323-343.

Glicken, J. (1999) Effective public involvement in public decisions. *Science Communication*, 20(3), 298-327.

Godin, B. (2001) The emergence of science and technology indicators: why did governments supplement statistics with indicators? Project on History and Sociology of S&T Statistics, *Working Paper No. 8*. Montreal, Canada.

Godin, B. (2002) Outline for a history of science measurement. *Science, Technology & Human Values*, 27(3), 3-27.

Godin, B. (2003) 'The Knowledge-based economy: conceptual framework or buzzword?' Project on History and Sociology of S&T Statistics, *Working Paper No. 24*. Montreal, Canada.

Godin, B. (2009) 'Making science, technology and innovation policy: conceptual frameworks as narratives'. Paper No. 41, *Presented at the Polish Academy of Sciences, Committee for the Science*, Warsaw, Poland, 2nd December. Published in *RICEC*, 1(1).

Godin, B. and Gingras, Y. (2000) What is scientific and technological culture and how is it measured? A multidimensional model. *Public Understanding of Science*, 9(1), 43-58.

Godin, B. and Dore, C. (2004) 'Measuring the impacts of science: beyond the economic dimension. *CSIIC Working Paper*, CSIIC, Canada.

Goldberg, M. (1995) Social marketing: are we fiddling while Rome burns? *Journal of Consumer Psychology*, 4(4), 347-370.

Goncalves, M. (2006) Transparency, openness and participation in science policy processes. In Guimaraes-Pereira, A., Guedes-Vaz, S. and Tognetti, S. (Eds) *Interfaces between Science and Society*. Sheffield, United Kingdom, Greenleaf Publishing Ltd, 176-184.

Gonzalez-Castro, F., Kellison, J., Boyd, S. and Kopak, A. (2010) A methodology fro conducting integrative mixed methods research and data. *Journal of Mixed Methods Research*, 4(4), 342-360.

Gordon, R., Mc Dermott, L., Stead, M. and Angus, K. (2006). The effectiveness of social marketing interventions for health improvement: what's the evidence? *Public Health*, 120, 1133-1139.

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

Greene, J. and Hall, J. (2010) Dialectics and pragmatism: being of consequence. In Tashakkori, A. and Teddlie, C. (Eds*) Sage Handbook of Mixed Methods in Social and Behavioural Research*, Thousand Oaks, California, Sage Publications Inc, 119-143.

Greene, J., Caracelli, V. and Graham, W. (1989) Toward a conceptual framework for mixed-method evaluation designs. *Educational Evaluation and policy Analysis*, 11(3), 255-274.

Gregory, J. and Miller, S. (1998) *Science in Public: Communication, Culture and Credibility*. Cambridge, MA, Perseus Books Group.

Gregory, J., Miller, S. and Palen, J. (1999) Review: science in the public eye. *BioScience*, 49(1), 75-76.

Gregson, J., Foerster, S., Orr, R., Jones, L., Benedict, J., Clarke, B., Hersey, J., Lewis, J. and Zotz, K. (2001) System, environmental, and policy changes: using the socio-ecological model as a framework for evaluating nutrition education and social marketing programs with low-income audiences. *Journal of Nutrition Education*, 33(1), 4-15.

Gronroos, C. (2004) The relationship marketing process: communication, interaction, dialogue, value. *Journal of Business and Industry Marketing*, 19(2), 99-113.

Guedes-Vaz, S. and Guimaraes-Pereira, A. (2006) Introduction, In Guimaraes-Pereira, A., Guedes-Vaz, S. and Tognetti, S. (Eds) *Interfaces between Science and Society*. Sheffield, United Kingdom, Greenleaf Publishing Ltd, 8-14.

Gulati, R. (1995) Does familiarity breed trust? The implications of repeated ties for contractual choice in alliances. *Academy of Management Journal*, 38(1), 85-112.

Gulati, R. and Gargiulo, M. (1999) Where do interorganizational networks come from? *American Journal of Sociology*, 104(5), 1439-1493.

Gulati, R. and Sytch, M. (2008) Does familiarity breed trust? Revisiting the antecedents of trust. *Managerial and Decision Economics*, 29, 165-190.

Gulati, R., Dialdin, D. and Wang, L. (2002) Organizational Networks in Baum, J.A.C (Ed). *Companion to Organizations*, Boston, Blackwell Publishers, 281-303.

Gulati, R., Nohria, N. and Zaheer, A. (2000) Strategic networks. *Strategic Management Journal*, 21(3), 203-215.

Guston, D. (2001) Boundary organisations in environmental policy and science: an introduction. *Science, Technology and Human Values*, 26(4), 399-408.

Hage, J., Jordan, G. and Mote, J. (2007) A theory based innovation systems framework for evaluating diverse portfolios of research part two: macro indicators and policy interventions. *Science and Public Policy*, 34(10), 731-741.

Hagendijk, R. and Irwin, A (2006) Public deliberation and governance: engaging wit science and technology in contemporary Europe. *Minerva*, 44, 167-184.

Hamel, G., Doz, Y. and Prahalad, C. (1989) Collaborate with your competitors and win. *Harvard Business Review*, 67(1), 133-139.

Hansen, M. (1999) The search-transfer problem: the role of weak ties in sharing knowledge across organisation subunits. *Administrative Science Quarterly*, 44(1), 82-111.

Hansen, A. (2009) Science, communication and media. In Holliman, R., Whitelegg, E., Scanlon, E., Smidt, S. and Thomas, J. (Eds) *Investigating Science Communication in the Information Age: Implications for Public Engagement and Popular Media*, Oxford, United Kingdom, Oxford University Press, 105-127.

Hardy, C., Philips, N. and Lawrence, T. (2003) Resources, knowledge and influence: the organisational effects of interorganisational collaboration. *Journal of Management Studies*, 40(2), 321-347.

Hastings, G. (2007) *Social Marketing – Why Should The Devil Have All The Best Tunes?* London, UK, Elsevier.

Hastings, G. and Domegan, C. (in press) *Social Marketing: Why Should the Devil Have all the Tunes? A few More Tunes, forthcoming 2nd Edition*, UK, Routledge.

Hastings, G. and Saren, M. (2003) The critical contribution of social marketing. *Marketing Theory*, 3(3), 305-322.

He, Z. and Wong, P. (2004) Exploration vs. exploitation: an empirical test of the ambidexterity hypothesis. *Organization Science*, 15(4), 481-494.

Henneberg, S., Mouzas, S. and Naude, P. (2006) Network pictures: concepts and representations. *European Journal of Marketing*, 40(3/4), 408-429.

Hennigan, M. (2012) *Irish Science Policy: 2020 replaces 2013 as target to be "best country in … world for scientific research*. Finfacts Ireland, Business and Finance Portal. Available at www.finfacts.ie [Accessed 27/11/2012].

Henriksen, E. and Froyland, M. (2000) The contribution of museums to scientific literacy: views from audience and museum professionals. *Public Understanding of Science*, 9(4), 393-415.

Hessels, L., VanLente, H. and Smits, R. (2009) In search of relevance: the changing contract between science and society. *Science and Public Policy*, 36(5), 387-401.

Hilliard, R. and Green, R. (2004) Governance and institutional change in Ireland. *MONIT Project*, Centre for Innovation and Structural Change, NUI, Galway.

Hinkin, T. (1995) A review of scale development practices in the study of organisations. *Journal of Management*, 21(5), 967-988.

Hinkin, T. (1998) A brief tutorial on the development of measures for use in survey questionnaires. *Organisational Research Methods*, 1(1), 104-121.

Hoek, J. and Jones, S. (2011) Regulation, public health and social marketing: a behaviour change trinity. *Journal of Social Marketing*, 1(1), 32-44.

Houston, F. and Gasseinheimer, J. (1987) Marketing and exchange. *Journal of Marketing*, 51(4), 3-18.

Huff, L. and Kelly, L. (2003) Levels of organisational trust in individualist versus collectivist societies: a seven-nation study. *Organisation Science*, 14(1), 81-90.

Hughes, M., Duane-Ireland, R. and Morgan, R. (2007) Stimulating dynamic value: social capital and business incubation as a pathway to competitive success. *Long Range Planning*, 40(1), 154-177.

Hulin, C. (2001) Measurement, *Journal of Consumer Psychology*, 10(1/2), 55-69.

Hult, G. and Ferrell, O. (1997) Global organisational learning capacity in purchasing: construct and measurement. *Journal of Business Research*, 40, 97-111.

Hunt, S. and Morgan, R. (1994) Relationship marketing in the era of network competition. *Marketing Management*, 3(1), 18-28.

Inkpen, A. and Tsang, E. (2005) Social capital, networks, and knowledge transfer. *Academy of Management Review*, 30(1), 146-165.

Inzelt, A. (2008) Private sector involvement in science and innovation policy-making in Hungary. *Science and Public Policy*, 35(2), 81-94.

Irwin, A. (2009) Moving forward in circles? Science communication and scientific governance in an age of innovation. In Holliman, R., Whitelegg, E., Scanlon, E., Smidt, S. and Thomas, J. (Eds) *Investigating Science Communication in the Information Age: Implications for Public Engagement and Popular Media*, Oxford, United Kingdom, Oxford University Press, 3-17.

Ivankova, N., Creswell, J. and Stick, S. (2006) Using mixed-methods sequential explanatory design: from theory to practice. *Field Methods*, 18(1), 3-20.

Ivens, B. and Blois, K. (2004) Relational exchange norms in marketing: a critical review of Macneil's contribution. *Marketing Theory*, 4(3), 239-263.

Jackson, R., Barbagallo, F. and Haste, H. (2005) Strengths of public dialogue on science-related issues. *Critical Review of International Social and Political Philosophy*, 8(3), 349-358.

Jacobson, N. (2007) Social epistemology: theory for the "fourth wave" of knowledge transfer and exchange research. *Science Communication*, 29(1), 116-127.

Janz, B. and Prasarnphanich, P. (2003) Understanding the antecedents of effective knowledge management: the importance of a knowledge-centred culture. *Decision Sciences*, 34(2), 351-384.

Jaworski, B., Kohli, A. and Sahay, A. (2000) Market-driven versus driving markets. *Journal of the Academy of Marketing Science*, 28(1), 45-54.

Jensen, E. and Holliman, R. (2009) Investigating science communication to inform science outreach and public engagement. In Holliman, R., Whitelegg, E., Scanlon, E., Smidt, S. and Thomas, J. (Eds) *Investigating Science Communication in the Information Age: Implications for Public Engagement and Popular Media*, Oxford, United Kingdom, Oxford University Press, 55-71.

Jerez-Gomez, P., Cespedes-Lorente, J. and Valle-Cabrera, R. (2005) Organisational learning capability: a proposal of measurement. *Journal of Business Research*, 58, 715-725.

Johnson, B. and Gray, R. (2010) A history of philosophical and theoretical issues for mixed methods research. In Tashakkori, A. and Teddlie, C. (Eds) *Sage Handbook of Mixed*

Methods in Social and Behavioural Research, Thousand Oaks, California, Sage Publications Inc., 69-94.

Johnson, R. and Onwuegbuzie, A. (2004) Mixed methods research: a research paradigm whose time has come. *Educational Researcher*, 33(7), 14-26.

Johnson, G., Scholes, K. and Whittington, R. (2006) *Exploring Corporate Strategy - Text and Cases, 7th Edition*. Harlow, England, Prentice Hall-Financial Times.

Jones, B. (2010) As science evolves, how can science policy? *Innovation Policy and the Economy*, 11, 1-31.

Juttner, U. and Wehrli, H. (1994) Relationship marketing from a value system perspective. *International Journal of Service Industry Management*, 5(5), 54-73.

Kale, P. and Singh, H. (2007) Building firm capabilities through learning: the role of the alliance learning process in alliance capability and firm-level alliance success. *Strategic Management Journal*, 28, 981-1000.

Kaplowitz, M., Hadlock, T. and Levine, R. (2004) A comparison of web and mail survey response rates. *Public Opinion Quarterly*, 68(1), 94-101.

Katsamakas, E. (2007) Knowledge processes and learning options in networks: evidence form telecommunications. *Human Systems Management*, 26, 181-192.

Kennedy, A. and Parsons, A. (2012) Macro-social marketing and social engineering: a systems approach. *Journal of Social Marketing*, 2(1), 37-51.

Kim, H. (2007) PEP/IS: a new model for communicative effectiveness of science. *Science Communication*, 28(3), 287-313.

Kisby, B. (2007) Analysing policy networks – towards an ideational approach. *Policy Studies*, 28(1), 71-90.

Klint, M. and Sjoberg, U. (2003) Towards a comprehensive SCP- model for analysing strategic networks/alliances. *International Journal of Physical Distribution and Logistics Management*, 33(5), 408-426.

Knight, T. and Barnett, J. (2010) Perceived efficacy and attitudes towards genetic science and science governance. *Public Understanding of Science*, 19(4), 386-402.

Koka, B. and Prescott, J. (2002) Strategic alliances as social capital: a multidimensional view. *Strategic Management Journal*, 23(9), 795-816.

Kong, E. (2010) Innovation processes in social enterprises: an IC perspective. *Journal of Intellectual Capital*, 11(2), 158-178.

Kramer, D. and Wells, R. (2005) Achieving buy-in: building networks to facilitate knowledge transfer. *Science Communication*, 26(4), 428-444.

Krosnick, J. (1999) Survey research. *Annual Review of Psychology*, 50, 537-567.

Kurath, M. and Gisler, P. (2009) Informing, involving or engaging? Science communication, in the ages of atom-, bio- and nanotechnology. *Public Understanding of Science,* 18(5), 559-573.

Langlois, R. (1983) Systems theory, knowledge, and the social sciences. In Fritz Machlup, F. and Mansfield, U. (Eds) *The Study of Information: Interdisciplinary Messages*. New York: John Wiley, 581-600.

Leach, J., Yates, S. and Scanlon, E. (2009) Models of science communication. In Holliman, R., Whitelegg, E., Scanlon, E., Smidt, S. and Thomas, J. (Eds) *Investigating Science Communication in the Information Age: Implications for Public Engagement and Popular Media*, Oxford, United Kingdom, Oxford University Press, 128-146.

Lee, S., Olson, D. and Trimi, S. (2012) Co-innovation: convergenomics, collaboration and co-creation for organisational values. *Management Decision*, 50(5), 817-831.

Lee, C., Scheufele, A. and Lewenstein, B. (2005) Public attitudes towards emerging technologies: examining the interactive effects of cognitions and affect on public attitudes toward nanotechnology. *Science Communication*, 27(2), 240-267.

Lefebvre, R. (2000) Theories and models in social marketing. Available at: http://socialmarketing.blogs.com/Publications/Theoretical_Models_in_Social_Marketing.pdf [Accessed 18/08/09].

Lefebvre, R. (2009) The change we need: new ways of thinking about social issues. *Social Marketing Quarterly*, 15 (3), 142-144.

Lefebvre, R. (2011) An integrative model for social marketing. *Journal of Social Marketing*, 1(1), 54-72.

Lefebvre, R. (2012) Transformative social marketing: co-creating the social marketing discipline and brand. *Journal of Social Marketing*, 2(2), 118-129.

Lefebvre, R. and Flora, J. (1988) Social marketing and public health intervention. *Health Education Quarterly*, 15(3), 299-315.

Lengwiler, M. (2008) Participatory approaches in science and technology: historical origins and current practices in critical perspective. *Science, Technology & Human Values*, 33(2), 186-200.

Lewenstein, B.V. (2005) Models of Public Communication of Science and Technology. Available at: http://communityrisks.cornell.edu/backgroundmaterials/lewenstein2003.pdf [Accessed 24/06/2010].

Lewis, R. and Erickson, L. (1969) Marketing functions and marketing systems: a synthesis. *Journal of Marketing*, 33(1), 10-14.

Lepori, B., Barre, R. and Filliatreau, G. (2008) New perspectives and challenges for the design and production of S&T indicators. *Research Evaluation*, 17(1), 33-44.

Lin, Z., Yang, H. and Arya, B. (2009) Alliance partners and firm performance: resource complementarity and status association. *Strategic Management Journal*, 30, 921-940.

Logan, R. (2001) Science mass communication: its conceptual history. *Science Communication*, 23(2), 135-163.

Lomnicki, A. (1992) Population ecology from the individual perspective. In DeAngelis, D. and Gross, L. (Eds) *Individual-Based Models and Approaches in Ecology*. New York, Chapman and Hall, 3-17.

Luck, D. (1974) Social marketing: confusion compounded. *Journal of Marketing*, 38(4), 70-72.

Lujan, J. and Todt, O. (2007) precaution in public: the social perception of the role of science and values in policy making. *Public Understanding of Science*, 16(1), 97-109.

Lundvall, B. (2007) National innovation systems – analytical concept and development tool. *Industry and Innovation*, 14(1), 96-119.

Lusch, R. and Webster, F. (2010) *Marketing's Responsibility for the Value of the Enterprise*. Marketing Science Institute Working Paper Series 2010, Report No. 10-111.

Lusch, R., Vargo, S. and O'Brien, M. (2007) Competing through service: insights from service dominant logic. *Journal of Retailing*, 83(1), 5-18.

Lusch, R., Vargo, S. and Tanniru, M. (2010) Service, value networks and learning. *Journal of the Academy of Marketing Science*, 38(1), 19-31.

Lyall, C. (2007) Changing boundaries: the role of policy networks in the multi-level governance of science and innovation in Scotland. *Science and Public Policy*, 34(1), 3-14.

Maak, T. (2007) Responsible leadership, stakeholder engagement, and the emergence of social capital. *Journal of Business Ethics*, 74(1), 329-343.

Maibach, E. (2002) Explicating social marketing: what is it, and what isn't it? *Social Marketing Quarterly*, 8(4), 7-13.

Malchimp (2012) Email Marketing Benchmarks. Available at: http://mailchimp.com/resources/research/email-marketing-benchmarks-by-industry/ [Accessed 10/03/2012].

Malhotra, N. (2010) *Marketing Research: An Applied Orientation, 6th Edition*. Upper Saddle River, New Jersey, Pearson Education, Inc.

Manzini, S. (2003) Effective communication of science in a culturally diverse society. *Science Communication*, 25(2), 191-197.

Marques, S. (2008*) Creating Value through Relationships: A Critical Contribution from Social Marketing*. Ph.D. Thesis, University of Stirling.

Marques, S. and Domegan, C. (2011) Relationship marketing and social marketing. In Hastings, G., Angus, K. and Bryant, C. (Eds) The Sage Handbook of Social Marketing, London, UK, Sage Publication, 44-60.

Martin-Sempere, M., Garzon-Garcia, B. and Rey-Rocha, J. (2008) Scientists' motivation to communicate science and technology to the public: surveying participants at the Madrid science fair. *Public Understanding of Science*, 17(3), 349-367.

Mavondo, F. and Rodrigo, E. (2001) The effect of relationship dimensions on interpersonal and interorganisational commitment in organisations conducting business between Australia and China. *Journal of Business Research*, 52, 111-121.

McCay, B. (1978) Systems ecology, people ecology and the anthropology of fishing communities. *Human Ecology*, 6(4), 397-422.

McGuire, M. and Olson, M. (1996) the economics of autocracy and majority rule; the invisible hand and the use of force. *Journal of Economic Literature*, 34(1), 72-96.

McKee, D. and Wang, G. (2006) Economic versus social exchange in marketing places: an empirical study among manufacturing firms. *Journal of Business Research*, 59(4), 397-406.

McKenzie-Mohr, D. and Smith, W. (1999) *Fostering Sustainable Behaviour: An Introduction to Community-Based Social Marketing*, Gabriola Island, BC, Canada, New Society Publishers.

McLeroy, K., Bibeau, D., Steckler, A. and Glanz, K. (1988) An ecological perspective on health promotion programmes. *Health Education Quarterly*, 15(4), 351-377.

Mesquita, L., Anand, J. and Brush, T. (2008) Comparing the resource-based and relational views: knowledge transfer and spillover in vertical alliances. *Strategic Management Journal*, 29, 913-941.

Meulman, J. and Heiser, W. (2004) *SPSS Categories 13.0*, USA, SPSS Inc.

Michael, M. (2009) Publics performing publics: of PiGs, PiPs and politics. *Public Understanding of Science*, 18(5), 617-631.

Milbergs, E. and Vonortas, N. (2004) *Innovation Metrics: Measurement to Insight.* Centre for Accelerating Innovation and George Washington University. National Innovation Initiative 21st Century Working Group.

Millar, M. and Dillman, D. (2011) Improving response to web and mixed-mode surveys. *Public Opinion Quarterly*, 75(2), 249-269.

Miller, J. (1992) Toward a scientific understanding of the public understanding of science and technology. *Public Understanding of Science*, 1, 23-26.

Miller, S. (2001) Public understanding of science at the crossroads. *Public Understanding of Science*, 10(1), 115-120.

Miller, J. (2004) Public understanding of, and attitudes toward, scientific research: what we know and what we need to know. *Public Understanding of Science*, 13(3), 273-294.

Miller, S., Fahy, D. and ESConet Team, (2009) Can science communication workshops train scientists for reflexive public engagement? The ESConet Experience. *Science Communication*, 31(1), 116-126.

Mitchell, W. and Singh, K. (1996) Survival of business using collaborative relationships to commercialize complex goods. *Strategic Management Journal*, 17(3), 169-195.

Mitsuishi, S., Kato, K. and Nakamura, K. (2001) A new way to communicate science to the public: the creation of the scientist library. *Public Understanding of Science*, 10(2), 231-241.

Mogendorff, K., Molder, H., Gremmen, B. And Van Woerkum, C. (2012) "Everyone may think whatever they like, but scientists …": or how and to what end plant scientists manage the science-society relationship. *Science Communication*, 34(6), 727-751.

Molina-Azor, J. (2011) The use and added value of mixed methods in management research. *Journal of Mixed Methods Research*, 5(1), 7-24.

Moorman, C. (1995) Organisational market information processes: cultural antecedents and new product outcomes. *Journal of Marketing Research*, 32(3), 318-335.

Moorman, C., Deshpande, R. and Zaltman, G. (1993) Factors affecting trust in market research relationships. *Journal of Marketing*, 57, 81-101.

Morgan, D. (2007) Paradigms lost and pragmatism regained: methodological implications of combining qualitative and quantitative methods. *Journal of Mixed Methods Research*, 1(1), 48-76.

Morgan, R. and Hunt, S. (1994) The commitment-trust theory of relationship marketing. *Journal of Marketing*, 58(3), 20-38.

Mu, J. Peng, G. and Love, E. (2008) Interfirm networks, social capital and knowledge flow. *Journal of Knowledge Management*, 12(4), 86-100.

Muthusamy, S. and White, M. (2005) Learning and knowledge transfer in strategic alliances: a social exchange view. *Organization Studies*, 26(3), 415-441.

Nguyen, P. (2010) Author guidelines for reporting scale development and validation results in the journal of the society for social work and research. *Journal of the Society for Social Work and Research*, 1(2), 99-103.

Nill, J. and Kemp, R. (2009) Evolutionary approaches for sustainable innovation policies: from niche to paradigm? *Research Policy*, 38, 668-680.

Nonaka, I. (1994) A dynamic theory of organisational knowledge creation. *Organisation Science*, 5(1), 14-37.

Nonaka, I., Toyama, R. and Konno, N. (2000) SECI, Ba and Leadership: a unified model of dynamic knowledge creation. *Long Range Planning*, 33, 5-34.

Nooteboom, B. (2000) Institutions and forms of coordination in innovation systems. *Organizational Studies*, 21(5), 915-939.

Nooteboom, B., Berger, H. and Noorderhaven, N. (1997) Effects of trust and governance on relational risk. *Academy of Management Review*, 40(2), 308-338.

Onwuegbuzie, A. and Collins, K. (2007) A typology of mixed methods sampling designs in social science research. *The Qualitative Report*, 12(2), 281-316.

O'Shaughnessy, N. (1996) Social Propaganda and social marketing: a critical difference? *European Journal of Marketing*, 30(10/11), 54-67.

Pallett, H. (2012) *The (Re)publics of Science: Changing Policy and Participation*. 3S Working Paper 2012-04. Norwich: Science, Society and Sustainability Research Group.

Palmatier, R. (2008) Interfirm relational drivers of customer value. *Journal of Marketing*, 72(1), 76-89.

Palmer, A. (1994) Relationship marketing: back to basics? *Journal of Marketing Management*, 10, 571-579.

Palmer, A. (1996) Relationship marketing: a universal paradigm or management fad? *The Learning Organization*, 3(3), 18-25.

Pardo, R. and Calvo, F. (2002) Attitudes towards science among the European public: a methodological analysis. *Public Understanding of Science*, 11(2), 155-195.

Pardo, R. and Calvo, F. (2006) Mapping perceptions of science in end-of-century Europe. *Science Communication*, 28(1), 3-46.

Parung, J. and Bititci, U. (2006) A conceptual metric for managing collaborative networks. *Journal of Modelling in Management*, 1(2), 116-136.

Peattie, S. and Peattie, K. (2003) Ready to fly solo? Reducing social marketing's dependence on commercial marketing theory. *Marketing Theory*, 3(3), 365-385.

Pelkonen, A., Teravainen, T. and Waltari, S. (2008) Assessing policy coordination capacity: higher education, science, and technology policies in Finland. *Science and Public Policy*, 35(4), 241-252.

Pencheon, D. (2008) *The Good Indicators Guide: Understanding how to Use and Choose Indicators*. NHS Institute for Innovation and Improvement, Coventry, UK.

Perkmann, M. and Walsh, K. (2007) University-industry relationships and open innovation: towards a research agenda. *International Journal of Management Reviews*, 9(4), 259-280.

Peteraf, M. (1993) The cornerstones of competitive advantage: a resource-based view. *Strategic Management Journal*, 14(3), 179-191.

Pingree, S., Hawkins, R. and Botta, R. (2000) The effect of family communication patterns on young people's science literacy. *Science Communication*, 22(2), 115-132.

Poliakoff, E. and Webb, T. (2007) What factors predict scientists' intentions to participate in public engagement of science activities? *Science Communication*, 29(2), 242-263.

Porter, S. and Whitcomb, M. (2003) The impact of contact type on web survey response rates. *Public Opinion Quarterly,* 67, 579-588.

Powell, M. and Colin, M. (2008) Meaningful citizen engagement in science and technology: what would it really take? *Science Communication*, 30(1), 126-136.

Powell, M. and Kleinman, D. (2008) Building citizen capacities for participation in nanotechnology decision-making: the democratic virtues of the consensus conference model. *Public Understanding of Science*, 17(3) 329-348.

Powell, W., Koput, K. and Smith-Doer, L. (1996) Interorganizational collaboration and the locus of innovation: networks of learning in biotechnology. *Administrative Science Quarterly*, 41(1), 116-145.

Prahalad, C. and Krishnan, M. (2008) *The New Age of Innovation – Driving Co-Created Value through Global Networks*. New York, USA, McGraw-Hill.

Prahalad, C. and Ramaswamy, V. (2004) Co-creation experiences: the next practice in value creation. *Journal of Interactive Marketing*, 18(3), 5-14.

Prahalad, C. and Venkat, R. (2004) Co-creating unique value with customers. *Strategy and Leadership*, 32(3), 4-9.

Provan, K., Fish, A. and Sydow, J. (2007) Interorganisational networks at the network level: a review of the empirical literature on whole networks. *Journal of Management*, 33(3), 479-516.

Pulzl, H. and Rametsteiner, E. (2009) Indicator development as 'boundary spanning' between scientists and policy makers. *Science and Public Policy*, 36(10), 743-752.

Pyka, A. (2002) Innovation networks in economics: from the incentive-based to the knowledge-based approaches. *European Journal of Innovation Management,* 5(3), 152-163.

Rattray, J. and Jones, M. (2007) Essential elements of questionnaire design and development. *Journal of Clinical Nursing*, 16, 234-243.

Reidenbach, R. and Oliva, T. (1983) General systems theory and the development of marketing thought. *Proceedings from the First Conference on Historical Analysis and Research in Marketing (CHARM)*, 1, 170-181.

Reinholt, M., Pedersen, T. and Foss, N. (2011) Why a central network position isn't enough: the role of motivation and ability for knowledge sharing in employee networks. *Academy of Management Journal*, 54(6), 1277-1297.

Rimer, B. and Glanz, K. (2005) *Theory at a Glance: A Guide for Health Promotion Practice, 2nd Edition.* National Cancer Institute, US Department of Health and Human Services; National Institutes of Health.

Roberts, N. (2000) Wicked problems and network approaches to resolution. *International Public Management Review*, 1(1), 1-19.

Roberts, N. (2004) Public deliberation in an age of direct citizen participation. *The American Review of Public Administration*, 34(4), 315-353.

Roberts, N. (2011) Beyond smokestacks and silos: open-source, web-enabled coordination in organisations and networks. *Public Administration Review*, 71(5), 677-693.

Rose, A. and McNiven, C. (2007) Biotechnology: from measures of activities, linkages and outcomes to impact indicators. In *Science, Technology and Innovation Indicators in a Changing World – Responding to Policy Needs*. Organisation for Economic Co-operation and Development Statistics Publications, Paris, France, 215-230.

Rose, S., Shipp, S., Lal, B. and Stone, A. (2009) *Frameworks for Measuring Innovation: Initial Approaches*. Institute for Defence Analysis, Science and Technology Policy Institute, Washington D.C.

Rothaermel, F. and Hess, A. (2007) Building dynamic capabilities: innovation driven by individual-, firm-, and network-level effects. *Organization Science*, 18(6), 898-921.

Rowe, G., Poortinga, W. and Pidgeon, N. (2006) A comparison of responses to internet and postal surveys in a public engagement context. *Science Communication*, 27(3), 352-375.

Rowley, T. (1997) Moving beyond dyadic ties: a network theory of stakeholder influences. *Academy of Management Review*, 22(4), 887-910.

Russell-Bennett, R., Previte, J. and Zainuddin, N. (2009) Conceptualising value creation for social change management. *Australasian Marketing Journal*, 17(4), 211-218.

Sallis, J., Owen, N. and Fisher, E. (2008) Ecological models of health behaviour. In Glanz, K., Rimer, B.K. and Viswanath, K. (Eds) *Health Behaviour and Health Education: Theory, Research and Practice, 4th Edition*, San Francisco, John Wiley & Sons, Inc., 465-486.

Sallis, J., Cervero, R., Ascher, W., Henderson, K., Kraft, K. And Kerr, J. (2006) An ecological approach to creating active living communities. *Annual Review of Public Health*, 27, 297-322.

Sandelowski, M. (2000) Focus on research methods – combining qualitative and quantitative sampling, data collection, and analysis techniques in mixed-method studies. *Research in Nursing and Health*, 23, 246-255.

Schafer, M. (2009) From public understanding to public engagement: an empirical assessment of changes in science coverage. *Science Communication*, 30(4), 475-505.

Schmitt, N. (1996) Uses and abuses of coefficient alpha. *Psychological Assessment*, 8(4), 350-353.

Science for All Expert Group (2010). Available at: http://interactive.bis.gov.uk/scienceandsociety/site/science-for-all [Accessed 10/04/2012].

Schnabel, U. (2003) God's formula and devil's contribution: science in the press. *Public Understanding of Science*, 12(3), 255-259.

Serrat, O. (2010) The future of social marketing. *Knowledge Solutions*, 73, 1–10.

Seufert, A., vonKrogh, G. and Bach, A. (1999) Towards knowledge networking. *Journal of Knowledge Management*, 3(3), 180-190.

Shah, R. and Swaminathan, V. (2008) Factors influencing partner selection in strategic alliances: the moderating role of alliance context. *Strategic Management Journal*, 29, 471-494.

Sheth, J. and Uslay, C. (2007) Implications of the revised definition of marketing: from exchange to value creation. *Journal of Public Policy and Marketing*, 26(2), 302-307.

Silverman, B. and Baum, J. (2002) Alliance-based competitive dynamics. *Academy of Management Journal*, 45(4), 791-806.

Sirilli, G. (1999) Innovation indicators in science and technology evaluation. *Scientometrics*, 45(3), 439-443.

Sless, D. and Shrensky, R (2001) Conversations in a landscape pf science and magic: thinking about science communication. In Stocklmayer, S.M, Gore, M.M. and Bryant, C. (Eds) *Science Communication in Theory and Practice*, The Netherlands, Kluwer Academic Publishers, 97-105.

Smith, K. (2000) 'Innovation Indicators and the Knowledge Economy: Concepts, Results and Policy Challenges'. Group for Studies in Technology, Innovation and Economic Policy, *STEP Group Working Paper*, Oslo, Norway.

Smith, W. (2002) Social marketing and its potential contribution to a modern synthesis of social change. *Social Marketing Quarterly*, 8(2), 46-48.

Smith, M. (2006) Social capital and intentional change. *Journal of Management Development*, 25(7), 718-731.

Sourial, N, Wolfson, C., Zhu, B., Quail, J., Fletcher, J., Karunananthan, S., Bandeen-Roche, K., Beland, F. and Bergman, H. (2010) Correspondence analysis is a useful tool to uncover the relationships among categorical variables. *Journal of Clinical Epidemiology*, 63, 638-646.

Stilgoe, J. and Wilsdon, J. (2009) The new politics of public engagement with science. In Holliman, R., Whitelegg, E., Scanlon, E., Smidt, S. and Thomas, J. (Eds) *Investigating Science Communication in the Information Age – Implications for Public Engagement and Popular Media*. New York, Oxford University Press, 18-34.

Stirling, A. (2006) From Science and Society to Science in Society: Towards a Framework for Co-Operative Research. *Directorate General Research and Technology Development, European Commission Workshop* - Brussels, November 24 - 25, 2005.

Stirling, A. (2008) Opening up and closing down: power, participation and pluralism in the social appraisal of technology. *Science, Technology & Human Values*, 33(2), 262-294.

Stoker, K. and Tusinki, K. (2006) Reconsidering public relations' infatuation with dialogue: why engagement and reconciliation can be more ethical than symmetry and reciprocity. *Journal of Mass Media Ethics*, 21(2/3), 156-176.

Stone, A., Rose, S., Lal, B. and Shipp, S. (2008) *Measuring Innovation and Intangibles: A Business Perspective*. Institute for Defence Analysis, Science and Technology Policy Institute, Washington D.C.

Story, M., Neumark-Sztainer, D. and French, S. (2002) Individual and environmental influences on adolescent eating behaviours. *Supplement to the Journal of The American Dietetic Association*, 102(3), 40-51.

Sturgis, P. and Allum, N. (2004) Science in society: re-evaluating the deficit model of public attitudes. *Public Understanding of Science*, 13(1), 55-74.

Swyngedouw, E. (2000) Authoritarian governance, power, and the politics of rescaling. *Environment and Planning*, 18, 63-76.

Tabanico, J. and Schultz, P. (2007) Community-based social marketing. *BioCycle*, 48(8), 41-44.

Tashakkori, A. and Teddlie, C. (1998) Introduction to mixed methods and mixed model studies in the social and behavioural science. In Plano-Clark, V. and Creswell, J. (Eds; 2008) *The Mixed Methods Reader*, Thousand Oaks, California, Sage Publications Inc, 7-26.

Teddlie, C. and Tashakkori, A. (2006) A general typology of research designs featuring mixed methods. *Research in the Schools*, 13(1), 12-28.

Teddlie, C. and Yu, F. (2007) Mixed methods sampling: a typology with examples. *Journal of Mixed Methods Research*, 1(1), 77-100.

Thomas, J., Sussman, S. and Henderson, J. (2001) Understanding strategic learning: linking organizational learning, knowledge management and sensemaking. *Organization Science*, 12(3), 331-345.

Thune, T. (2007) University-industry collaboration: the network embeddedness approach. *Science and Public Policy*, 34(3), 158-168.

Tichy, N., Tushman, M. and Fombrun, C. (1979) Social network analysis for organisations. *The Academy of Management Review*, 4(4), 507-519.

Tidd, J. and Bessant, J. (2009) *Managing Innovation – Integrating Technological, Market and Organisational Change, 4th Edition*. England, UK, John Wiley and Sons Ltd.

Tiwana, A. (2008) Do bridging ties complement strong ties? An empirical examination of alliance ambidexterity. *Strategic Management Journal*, 29, 251-272.

Tlili, A. and Dawson, E. (2010) Mediating science and society in the EU and UK: from information-transmission to deliberative democracy? *Minerva*, 48(1), 429-461.

Treise, D. and Weigold, M. (2002) Advancing science communication: a survey of science communicators. *Science Communication*, 23(3), 310-322.

Trench, B. (2008) Towards an analytical framework of science communication models. *Communicating Science in Social Contexts*, 1, 119-135.

Tsai, W. (2001) Knowledge transfer in intraorganisational networks: effects of network position and absorptive capacity on business unit innovation and performance. *Academy of Management Review*, 44(5), 996-1004.

Tuomi, I. (2012) Foresight in an unpredictable world. *Technology Analysis and Strategic Management*, 24(8), 735-751.

Turner, S. (2008) School science and its controversies; or, whatever happened to scientific literacy? *Public Understanding of Science*, 17(1), 55-72.

Tytler, R., Duggan, S. and Gott, R. (2001) Public participation in an environmental dispute: implications for science education. *Public Understanding of Science*, 10(4), 343-364.

Tzokas, N. and Saren, M. (1997) Building relationship platforms in consumer markets: a value chain approach. *Journal of Strategic Marketing*, 5(2), 105-120.

Umbach, P. (2004) Web surveys: best practices. *New Directions for Institutional Research*, 121, 23-38.

Uzzi, B. (1997) Social structure and competition in interfirm networks: the paradox of embeddedness. *Administrative Science Quarterly*, 42(1), 35-67.

Uzzi, B. and Lancaster, R. (2003) Relational embeddedness and learning: the case of bank loan managers and their clients. *Management Science*, 49(4), 383-399.

Van der Hove, S. (2007) A rationale for science-policy interfaces. *Futures*, 39, 807-826.

Van der Hove, S. and Sharman, M. (2006) Interfaces between science and policy for environmental governance: lessons and open questions from the European platform for biodiversity research strategy. In Guimaraes-Pereira, A., Guedes-Vaz, S. and Tognetti, S. (Eds) *Interfaces between Science and Society*. Sheffield, United Kingdom, Greenleaf Publishing Ltd, 185-208.

Van der Sanden, M. and Meijman, F. (2008) Dialogue guides awareness and understanding of science: an essay on different goals of dialogue leading to different science communication approaches. *Public Understanding of Science*, 17(1), 89-103.

Van der Sluijs, J. (2007) *Post Normal Science: Working Deliberating within imperfections.* Available at: http://www.nusap.net/downloads/PNS_SG_Wageningen_21Mar07.pdf [Accessed 05/02/2010].

Vargo, S. and Lusch, R. (2008) Service-dominant logic: continuing the evolution. *Journal of the Academy of marketing Science,* 36(1), 1-10.

Vargo, S. and Lusch, R. (2010) It's all B2B … and beyond: Toward a systems perspective on the market. *Industrial Marketing Management*, 40(2), 181-187.

Vargo, S., Maglio, P. and Archpru-Akaka, M. (2008) On value and value co-creation: a services system and service logic perspective. *European Management Journal*, 26(1), 145-152.

Walker, G., Kogut, B. and Shan, W. (1997) Social capital, structural holes and the formation of an industry network. *Organisation Science*, 8(2), 109-125.

Watermeyer, R. (2012) Measuring the impact values of public engagement in medical contexts. *Science Communication*, 34(6), 752-775.

Weigold, M. (2001) Communicating science: a review of the literature. *Science Communication*, 23(2), 164-193.

Wheeldon, J. (2010) Mapping mixed methods research: methods, measures and meaning. *Journal of Mixed Methods Research*, 4(2), 87-102.

Widen-Wulff, G. and Ginman, N. (2004) Explaining knowledge sharing in organisations through the dimensions of social capital. *Journal of Information Science*, 30(5), 448-458.

Wiebe, G. (1951) Merchandising commodities and citizenship on television. *Public Opinion Quarterly*, 15(4), 679-691.

Williams, J. and Kumanyika, S. (2002) Is social marketing an effective tool to reduce health disparities? *Social Marketing Quarterly*, 8(4), 14-31.

Williams, N., Onsman, A. and Brown, T. (2010) Exploratory factor analysis: a five step guide for novices. *Journal of Emergency Primary Health Care*, 8(3), 1-13.

Wilsdon, J. and Willis, R. (2004) *See Through Science – Why Public Engagement Needs to Move Upstream*. London, UK, Demos.

Wilsdon, J., Wynne, B. and Stilgoe, J. (2005) *The Public Value of Science or How to Ensure that Science Really Matters*. London, UK, Demos.

Winter, E. (2004) Public communication of science and technology: German and European perspectives. *Science Communication*, 25(3), 288-293.

Wolcott, S. and Sengupta, A. (2010) *Learning for change in public, educational and other science organisations: embedding greater public engagement – critical challenges and lessons emerging from literature review*. Department for Business, Innovation and Skills, UK.

Woodruff, R. and Flint, D. (2006) Marketing's service-dominant logic and customer value. In Lusch, R.F. and Vargo, S.L. (Eds) *The Service Dominant Logic of Marketing: Dialog, Debate and Directions*, New York, M.E. Sharpe, Inc., 183-195.

Wymer, W. (2011) Developing more effective social marketing strategies. *Journal of Social Marketing*, 1(1), 17-31.

Yaneva, A., Rabesandratana, T. and Greiner, B. (2009) Staging scientific controversies: a gallery test on science museums' interactivity. *Public Understanding of Science*, 18(1), 79-90.

Yang, H., Lin, Z. and Lin, Y. (2010) A multilevel framework of firm boundaries: firm characteristics, dyadic differences, and network attributes. *Strategic Management Journal*, 31, 237-261.

Yi, J. (2009) A measure of knowledge sharing behaviour: scale development and validation. *Knowledge Management Research and Practice*, 7, 65-81.

Yli-Renko, H., Autio, E. and Sapienza, H. (2001) Social capital, knowledge acquisition, and knowledge exploitation in young technology-based firms. *Strategic Management Journal*, 22(6/7), 587-613.

Zaheer, A. and Bell, G. (2005) Benefiting from network position: firm capabilities, structural holes and performance. *Strategic Management Journal*, 26, 809-825.

Zainuddin, N., Russell-Bennett, R. and Previte, J.A. (2007) Conceptualising a relational approach to value creation in a government service: implications for social marketing. In Sullivan-Mort, G. and Hume, M. (Eds) *Proceedings from Social Entrepreneurship, Social Change and Sustainability: 2007 International Nonprofit and Social Marketing Conference*, Brisbane, Australia, 123-129.

Zorn, T., Roper, J., Weaver, C. and Rigby, C. (2012) Influence in science dialogue: individual attitude changes as a result of dialogue laypersons and scientists. *Public Understanding of Science*, 21(7), 848-864.