BARRIERS IN THE TRANSITION FROM RESEARCH AND DEVELOPMENT TO COMMERCIALIZATION OF NANOTECHNOLOGY IN MALAYSIA

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Abstract

Malaysia has exhibited a profound interest, thus far lacking in the developmental concentration in the field of nanotechnology since the embryonic formation of the National Nanotechnology Initiative (NNI) in 2006. There have been evident barriers, which disconnect the Research and Development (R&D) and commercialization of this technology from spanning through a progressing and transcending flow of innovative efficiency. This thesis aims to: (i) To identify the critical barriers that constrain the R&D and commercialization of nanotechnology in Malaysia, and (ii) To provide recommendations for policy actions and future studies for nanotechnology R&D and commercialisation in Malaysia.

This thesis illustratively explains the author's design of various factors, distinctively developed through a series of time series - citation analyses of core referred journals from 1989 – 2014 (26 year period). Citation analyses were conducted manually since the main element embedded within the core subject theme of each paper was not explicitly detected through title headings by use of any software. Graphical mappings were designed to prove the existence of missing gaps in literature and how it was relevant to the construction of a conceptual framework and its associated building blocks. Missing gaps were identified in the area of:

I: The hybrid of comprehensive vs non-comprehensive education of nanotechnology

II: The distinct priorities of academia and industry and how it affects the R&D and commercialization of nanotechnology

III: The formation of R&D policy for nanotechnology

This thesis explains the conceptual framework design through the formation of building blocks functioning as individual units of structure composed to formulate a larger subject entity that interoperate with interdependent units found within the structural assemblage. This thesis also provides an explicit presentation of exploratory questions designed to guide the qualitative research study - design model. Sampling method via purposive sampling and triangulation have been explained in terms of reason, sampling size and methodology.

The findings establish that university researchers and students are undeniably the knowledge bearing assets required during the invention or discovery stage and prototyping or testing stage from R&D to the commercialization of nanotechnology. This thesis proves that there is an absolute need for a skilled and educated workforce trained within an array of levels bifurcating from nanotechnology to congregate the projected demand in the future. Apart from human capital and technological capability, aspects such as infrastructure and capital investment also come into play in the pursuit towards realising a solid bridge between R&D and commercialization of nanotechnology.

Considering that a lot of investments have been made in the area of science and technology, although not specifically in the area of nanotechnology development and not many significant results attained, the main implication of this study is that it unveils the key anomalies existing within the nanotechnology environment to give the government and policy makers reason to invest in developing solutions to prevent the occurance of bottlenecks. The main findings and recommendations indicate the urgency to prepare human capital in nanotechnology through education and training for the fulfilment of nanotechnology relevant research activities in the next ten years. Besides, it is crucial to

make known the total cost of key infrastructure required to undertake a nanotechnology research activity in preparation for financial apportionments by potential applicants, the parallel importance of patents and publications in universities, and its role in sustaining nanotechnology research. Furthermore, this thesis suggests that the needs in adopting a multidisciplinary approach in nanotechnology educational programme and the potential roles that can be played by the Malaysian government to assist universities in creating research opportunities in nanotechnology through University-Industry partnerships.

Abstrak

Malaysia telah menunjukkan minat yang mendalam dalam bidang teknologi nano, sejak pembentukan embrio Inisiatif Nanoteknologi Kebangsaan (NNI) pada tahun 2006. Akan tetapi, setakat ini, kepekatan pembangunan nanoteknologi serba kekurangan. Halangan - halangan yang didapati, jelas memutuskan bahawa sambungan diantara R & D dan pengkomersilan nanoteknologi tersekat daripada merangkumi pengaliran, perentasan dan kecekapan inovatif. Tesis ini bertujuan untuk: (i) Mengenalpasti halangan – halangan kritikal yang menyekat pengaliran innovatif daripada R & D hingga pengkomersilan teknologi nano di Malaysia (ii) Memberi cadangan untuk tindakan dasar kerajaan dan kajian untuk masa hadapan.

Melalui reka bentuk pengarang tesis, tesis ini menggambarkan pelbagai faktor tersendiri, yang telah dikenal pasti melalui siri analisis masa, berdasarkan rujukan teras jurnal dari tahun 1989 - 2014 (tempoh selama 26 tahun). Analisis petikan jurnal dijalankan tanpa menggunakan sebarang perisian kerana didapati elemen utama yang menyatukan tema subjek teras bagi setiap jurnal kertas tidak jelas dikesan melalui tajuk-tajuk jurnal. Pemetaan grafik direka bentuk untuk membuktikan bahawa terdapat jurang yang hilang melalui siri analisis masa dan bagaimana jurang yang dikenal pasti dikaitkan dengan konsep pembinaan kerangka pengarang tesis dan bagaimana blok - blok pembangunan adalah selari dengan objektif tesis ini. Jurang yang telah dikenalpasti adalah seperi berikut:

I: Hibrid komprehensif vs pendidikan nanoteknologi yang tidak menyeluruh

II: Keutamaan berbeza diantara akademik dengan industri dan bagaimana perbezaaan dari segi keutamaan memberi kesan kepada R & D dan pengkomersilan teknologi nano

III: Pembentukan dasar R & D untuk nanoteknologi

Tesis ini menjelaskan bentuk rangka kerja konseptual melalui pembentukan blok-blok pembangunan yang digunakan sebagai unit individu pembinaan untuk merumuskan sebuah entiti tertakluk lebih besar yang boleh saling beroperasi dengan unit pembinaan yang saling-bergantung antara satu sama lain. Blok-blok pembangunan telah dilabelkan dengan jelas dan rangka kerja konseptual telah digambarkan melalui pemetaan grafik. Tesis ini juga menyediakan satu gambaran yang jelas dari soal penerokaan untuk kajian kualitatif dan kajian reka bentuk model penulis tesis ini. Kaedah persampelan melalui persampelan "purposive" dan triangulasi telah dijelaskan dari segi sebab, saiz persampelan dan kaedah.

Hasil kajian menunjukkan bahawa penyelidik universiti dan pelajar tidak dapat dinafikan sebagai asset penting yang diperlukan semasa ciptaan atau peringkat penemuan dan peringkat prototaip atau ujian dari R & D kepada pengkomersilan teknologi nano perpotensi. Adalah jelas bahawa terdapat keperluan mutlak bagi tenaga kerja yang mahir dan berpendidikan dilatih dari segi pelbagai peringkat berhubung dengan bidang nanoteknologi bagi memenuhi permintaan pada masa datang. Selain daripada modal insan dan keupayaan teknologi, aspek seperti infrastruktur dan modal pelaburan juga penting dalam usaha ke arah merealisasikan jambatan yang mantap antara R & D dan pengkomersilan teknologi nano.

Memandangkan bahawa banyak pelaburan telah dibuat dalam bidang sains dan teknologi, walaupun tidak secara khusus di dalam bidang pembangunan teknologi nano dan tidak banyak keputusan penting yang telah dicapai, implikasi utama kajian ini telah mendedahkan anomali utama yang sedia ada di dalam persekitaran teknologi nano dan memberi sebab keperluan dasar kerajaan untuk melabur dalam membangunkan bidang nanoteknologi.

Penemuan utama dan cadangan yang telah dibentangkan dalam tesis ini, mendesak kerajaan untuk menyediakan modal insan dalam nanoteknologi melalui pendidikan dan latihan bagi memenuhi aktiviti penyelidikan nanoteknologi dalam masa sepuluh tahun. Selain itu, adalah penting bagi memaklumkan jumlah kos infrastruktur utama yang diperlukan untuk menjalankan aktiviti penyelidikan nanoteknologi dalam persediaan kewangan bagi pemohon yang berpotensi, kepentingan selari dari segi paten dan penerbitan di universiti, dan peranannya dalam mengekalkan penyelidikan nanoteknologi. Tambahan pula, tesis ini menunjukkan bahawa pendekatan pelbagai disiplin dalam nanoteknologi program pendidikan dan peranan penting kerajaan Malaysia diperlukan untuk membantu universiti dalam mewujudkan peluang-peluang penyelidikan dalam nanoteknologi melalui pengabungan Universiti-Industri.

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List of Abbreviations

NNI	National Nanotechnology Initiative
R&D	Research and Development
ANF	Asian Nano Forum
MP	Malaysia Plan
CoEs	Center of Excellences
nm	Nanometer
WoS	Web of Science
PEN	Project for Emerging Technologies
MRI	Magnetic Resonance Imaging
MEMS	Micro Electromechanical Systems
NEMS	Micro Electromechanical Systems
STM	Scannning Tunnelling Microscope
AFM	Atomic Force Microscope
TEM	Transmission Electron Microscope
HRTM	High Resolution Transmission Microscope
U-I	University - Industry
PI	Principle Investigator
SME	Small and Medium Enterprises
VR	Virtual Reality
JITE	Just in Time Education
IP	Intellectual Property
OECD	Organization for Economic Cooperation and Development

N&N	Nanoscience and Nanotechnologies
S&T	Science and Technology
DOS	Department of Statistics
MOSTI	Ministry of Science, Technology and Innovation
EPU	Economic Planning Unit
ASM	Academy Science of Malaysia
NND	National Nanotechnology Directorate
NNRC	Nanotechnology National Reseach Center
IHL	Institute of Higher Learning
IRPA	Intensification of Priority Research Areas
TTC	Technology Transfer Center
DTI	Department of Trade and Industry
NSF	National Science Foundation
SR	Strategic Research
IGS	Industry Research and Development Grant Scheme
MGS	Multimedia Super Corridor Research and Development Grant Scheme
DAGS	The Demonstrator Application Grant Scheme
IMP	Industrial Master Plan

CHAPTER 1: Introduction

1.1 Introduction

Malaysia has demonstrated an intense interest in the field of nanotechnology, since the infant formation of the National Nanotechnology Initiative (NNI) in 2006, but there have been barriers, which have triggered the disconnection between the research and development (R&D) and commercialization of this technology from producing efficacious, evolving and innovative outputs. Areas such as nanotechnology education and training, patent and publications, nanotechnology innovations, existing policies of emerging and established economies, collaborative linkages and innovation systems are evolving precursors in the field of nanotechnology around the world. This thesis provides an in-depth analysis of barriers that limit the innovative transition from nanotechnology R&D to commercialization.

The central subject, which is nanotechnology, is no stranger to the scientific community around the world, even though it remains a mysterious realm of unknown possibilities among the broad-spectrum of scientific faculties and a current oblivion, as far as the common public is concerned. This chapter will provide a portrayal of the number of nanotechnology based products that have infiltrated into the marketplace and the number of firms involved in the engineering, manufacturing, or marketing of these products. This chapter will draw the readers' attention to the observable datum, which palpably surfaced from governmental databases, indicating that Malaysia is neither spearheading nor following in close competition with other countries, which are successfully and actively transforming innovations from lab prototypes into fully-fledged products. A matter of fact, it is far-behind. It must also be stated, that based on governmental reports of various countries (which will be discussed further in Chapter 2), countries have suffered major pitfalls in bridging the R&D and commercialization of nanotechnology but nonetheless own several significant and successful R&D to commercial outputs to their name. Therefore, based on our own country's environmental setting and current-status of nanotechnology now, this thesis will analyse what are the barriers that obstruct the transition from nanotechnology lab prototypes from moving into the commercial arena from the perspective of 16 building blocks highlighted in Chapter 4 of this thesis.

The chapter begins by introducing the multifaceted nature of nanotechnology and the global trends of the nanotechnology industry. This is followed by explaining the economies of the nanotechnology in the context of Malaysia and global. This chapter also summarizes the (6) key stimuluses' that motivated the researcher (author of this thesis) to embark on this research and how, along with missing gaps identified through a critical analysis of literature and author's ideas, triggered the formation of the thesis conceptual framework and its associated building blocks. The other important aspects explained in this section are the research questions (RQs) and research objectives (ROs), research strategy, significance of study, expected contribution to theory, industry and policymakers and the key terms and definitions according to the defined usage of the researcher within the thesis text.

1.2 The Multifaceted Nature of Nanotechnology: An Evolution of a New Era

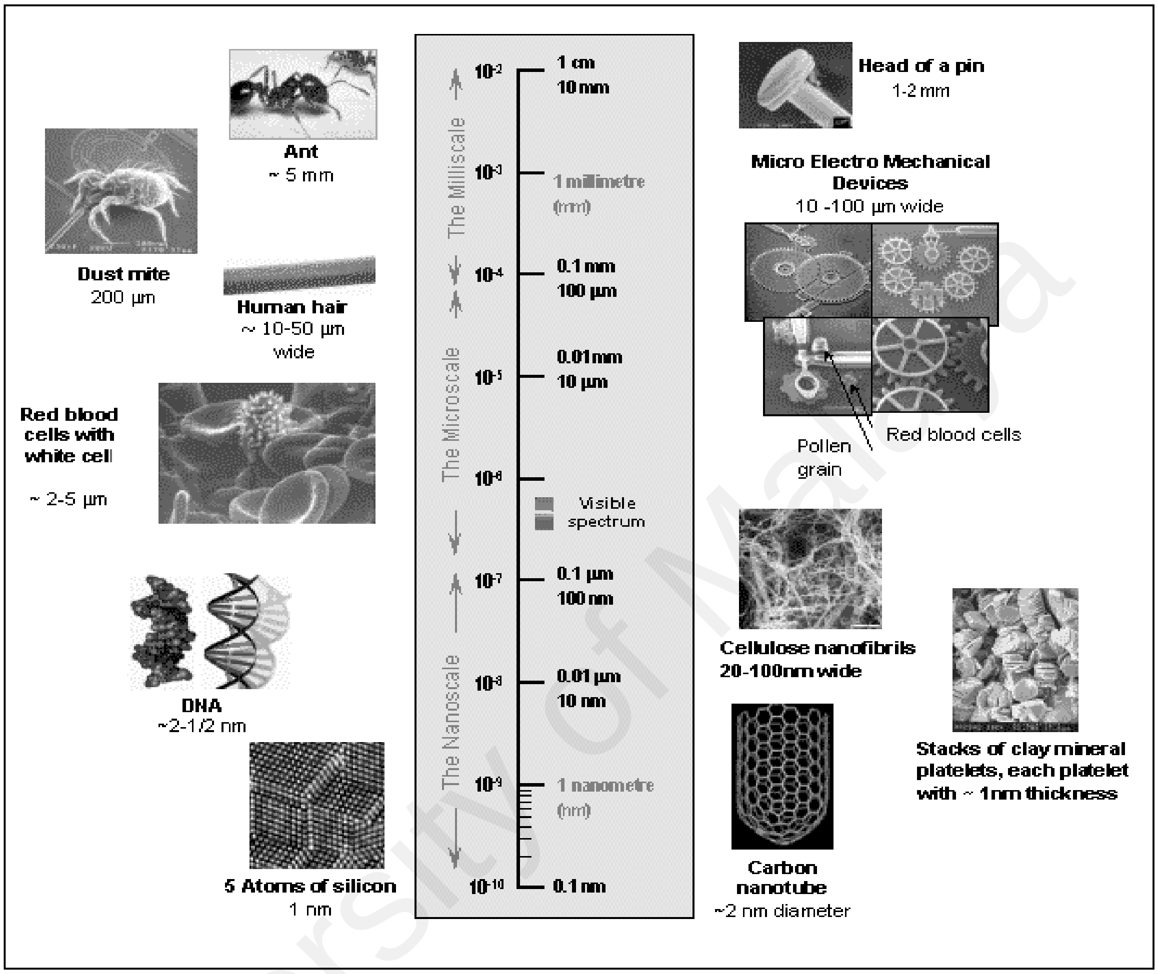
Prior to piercing into science's most unbelievable potential, which is nanotechnology, it is vital to primarily understand and assimilate what nanotechnology really means. Nanotechnology refers to scientific activity that occurs within the range of 1–100 nanometres[1]. It is a breakthrough field of technology that has evolved from micro to nano. Devoid of joining both nanoscience and nanotechnology terms together, to form a whole new term that probably would have resonated as ‘nanoscientech’, researchers worldwide have accepted the use of the term ‘nanotechnology’ instead, since both terms involve nanoscale and share a common prefix, which is ‘nano’.

Currently, there is no single, internationally agreed definition[2] for nanotechnology. According to the Royal Society and The Royal Academy of Engineering Report (2004), ‘nanoscience’ is concerned with understanding some phenomena (such as surface tension/properties, quantum effects and molecular assembly) and their influence on the properties of material. Simultaneously, according to the Royal Society and The Royal Academy of Engineering Report (2004), ‘nanotechnology’ aims to exploit these effects to create structures, devices and systems with novel and significantly improved properties and functions due to their size. To put it succinctly, nanotechnology is the application of nano-scientific developments that could deliver revolutionary advances that could transform or replace existing products and industries and create entirely new ones, which are lighter, faster, cheaper, safer and multi-functional (providing many capability features). Figure 1.1 shows the units of comparative measurements of nanometre.

[1] One (1) nanometre is one-billionth of a meter; in comparison, with the width of a single human hair is approximately 80,000 nanometers. One (1) nm is 80,000 times less than the width/diameter of a single human hair and generally aimed at constructing devices with atomic exactitude, whereas nanotechnology is a term encompassing nanoscale science, technology and engineering.

[2] The deficiency of standards and clear definition of the area of nanoscience and nanotechnology directs young scientists, PhD students in particular experience a misalignment between their research, their supervision, and the outcomes they have to generate (Battard, 2012).

Figure 1.1 Unit of Comparative Measurements to Nanometer (nm)



Source: Kumar (2008)

It is the engineering of tiny machines - the project ability to build things from the bottom up using techniques and tools, developed today to make complete, highly advanced products. This radical technology and continuously emerging industry known as nanotechnology, exploits the ultra-diminutive size, enabling the use of particles to deliver a range of profound and overriding benefits as highlighted in Table 1.1.

Table 1.1 Benefits of Nanotechnology

New Detection and Prevention Tools	Safety control and mechanisms
Medical Treatment Technologies	To reduce the rate of deaths and suffering from diseases like cancer and other deadly diseases
	Self-healing materials
	New organs to replace damaged and diseased ones
Clothing	Protects toxins and pathogens, stain resistant clothing
Clean and inexpensive renewable power through energy creation, storage and transmission technologies	
Universal access to safe water through portable, inexpensive water purification systems	
Energy sufficient, low emission “green” manufacturing systems	
High density memory systems	Storing the entire universal library collection
Health and nutrition	Reduce global hunger and malnutrition
Powerful, small, inexpensive sensors	Warn of minute levels of toxins and pathogens in the air, soil and water and alert the people to sudden changes in the environment
Health and fitness items	Filter ions, easily purify and recycle water
Lighter weight auto parts	Lighter weight cars that requires less fuel
Cosmetics	Sunscreen
National defence	Military applications
Space exploration	Space Elevator

Source: Wilson et al (2002), Kumar (2008), Pradeep (2008) Binns (2010) and Timp (1999)

As far as new firms and incumbents are concerned, nanotechnology can be thought about as a disruptive technology[3] that improves, although does not wholly replace the existing system; but has the capability to adapt with the existing system, and therefore two technologies can be acclimatized together to become one. To put it laconically, it has affected firms in a way that it has changed the way people deal with things. An important aspect bracketed together with nanotechnology, is its multidisciplinary nature, making it very intricate to pin down and aptly presage the future impact in any specific sector (Bhat, 2005). In addition, its applications have and will stretch through many economic sectors with diverging magnitude and impact formations on existing firms and industries (Linton and Walsh, 2004; Shea, 2005; Kostoff et al. 2007; Hullmann, 2007; Nikulainen and Palmberg, 2010; Juanola-Feliu, et al, 2012). As nanoscale science and technology (S&T)

[3] Disruptive technology is a term invented by Harvard Business School Professor Clayton M. Christensen to describe a new technology that unexpectedly displaces an established technology. In his 1997 best-selling book, "The Innovator's Dilemma," Christensen separates new technology into two categories: sustaining and disruptive. Sustaining technology relies on incremental improvements to an already established technology. Disruptive technology lacks refinement, often has performance problems because it is new, appeals to a limited audience, and may not yet have a proven practical application.

draws closer towards coercing escalating impacts on many aspects of our daily lives, the future prospects for careers in this field is also gradually emerging.

Other than being the first major worldwide research initiative (Mangematin & Walsh, 2012) and engine of growth (Palmberg, 2008) of the 21^{st} century, nanotechnology is the next biggest potential and “commercial opportunity” (Bozeman, et al 2007; Chih et al, 2012). To add support to this, Chih, et al (2012) underscores that commercialization is indispensable for the development of nanotechnology, which necessitates a high degree of market acceptance in terms of performance, reliability and economic requirements to augment the probability of survival and to amplify the yield of nano products.

Table 1.2 is a transcribed extract from a recording televised on the Discovery Channel, which provides a clear description of what nanotechnology really is today. It is a known fact that scientific genius does not always equal to commercial success. In order to benefit commercially from one’s research, it is important to take into account a myriad of factors. Among them are the environment, health and safety regulations, academy – industry cooperation, intellectual property and attracting investments, which come to play, well before and during the research process (Buchanan, et al, 2012). Therefore, the main purpose of this research study is to provide a diagnosis of barriers towards nanotechnology R&D and commercialization.

Table 1.2 What You Can't See: Nanotechnology

It is a science of the smallest scale with unbelievable potential. The nano world is a real experience that is going to impact our lives. Objects so tiny, is impossible to see them with the naked eye. The built-in materials of nanotech are made by rearranging atoms and molecules in different ways to create tubes, wires and particles - components as much 8,000 times smaller than a red blood cell. One of the most fun things is the construction of tiny apparatuses these individuals atoms and molecules that can perform functions within the human body and within the world. These invisible materials will enable us to do amazing things, maybe even cure cancer. In a first step, scientists are using gold - they found if they make nano-size spheres out of it, the gold will actually dissolve in the blood stream and move freely through the body. Many of the physical properties we measure in both materials actually change quite remarkably if you shrink the size of the object down to the nanometre scale. The tiny gold spheres are observed by tumour cells. Researchers then zap the gold with infrared waves that produce heat. The gold particles, which absorb the heat, will get very warm and the tumour will then decompose because of this additional heat. Curing cancer is still a ways off, but very soon, nanotechnology will have a huge impact on the green revolution. You can think of nanotechnology as being as the greenest approaches to revamping the infrastructure of our world. Scientist - Diana Huffacker is working on a superefficient solar cell that uses nano particles called quantum dots. *"We are talking about of being able to double the efficiency of the solar cell based on the use of quantum dots"*. In solar cells, the quantum dots are a 1000 times smaller than the width of human hair. A dot absorbs a single particle of light called a photon and then generates two (2) or three (3) electrons to create electrical current. This yields twice as much as power as standard solar cells. Solar can soon rival fossil fuels if this nanotech proves to be cheap and efficient. Meanwhile, scientists are developing a different green technology that employs invisible devices called nanowires to exploit the energy in the vibration your car makes. "*The wire will vibrate with the car and actually harvest that what would other waste vibrational energy and turn it to electricity"*. Another exciting nanotechnology comes from one of our common elements – carbon. Carbon nanotubes are made out of specialized hybrid molecule, where each carbon atom has a double bond to it to its nearest neighbour. Carbon nanotubes are 100 times stronger than steel. They are way, too small to see, but carbon nanotubes have the highest strength to weight ratio than any other known material. The most spectacular plans for carbon nanotubes will take us to new heights. A space elevator meant to transport payloads and people to outer space – the ultra strong, but also ultra lightweight material would be used to construct a super-strong ribbon than can support an elevator car. These cars may one day run between the ground and a space station. It is the idea that we can travel from earth to the space station, simply by climbing up the space elevator made out of carbon nanotubes. The elevator will eliminate the need for continuous rocket launches, which will devour lot of energy. Without a doubt, the micro world of nanotechnology will have a gigantic impact in our world.

Source: Transcribed extract from a recording televised from Discovery Channel (Astro Channel 554) entitled "What you can't See: Nanotechnology": 19.03.2012, 1330hrs

1.3 The Global Trends of the Nanotechnology Industry

Firms in the US, Europe, Japan and South Korea are all attempting to successfully pave way into becoming precursors of nanotechnology. The United States, Western Europe, Japan are among the developed countries showing a dominant force in nanotechnology research. Following in close lead are the developing countries like India, China and South Korea. Malaysia is also augmenting its efforts to make its mark in the global arena. As of 2008, more than 600 nanotechnology products were in the market, generally offering incremental improvements of existing products; more than half of which have been produced by companies based in United States[4]. The Project on Emerging Nanotechnologies (PEN[5])'s Nanotechnology Consumer Product Inventory has found that the number of manufacturer-identified nanotechnology-enabled consumer products that have entered the marketplace to date has increased to over 1,300. This number is not yet comprehensive because it has been difficult to find out how many "nano" consumer products are on the market and which merchandise to be called "nano". According to Lux Research[6], it is estimated that products incorporating nanotechnology produced $50 billion in global revenues in the year 2006 and by the year 2014, revenues will reach $2.6 trillion of projected global manufacturing output as depicted in Figure 1.2 (Science and Technology Policy Resources, Science and Industry Division, 2008).

Figure 1.2 Global Sales of Products Incorporating Nanotechnology (US$ Million)

	2004	2006	2008	2010	2012	2014
US $ Millions	12,986	51,631	150,138	507,738	1,410,479	2,572,883

Source: Lux Research, 2004 (Note: Year 2014 is a projection)

[4]According to the Science and Technology Policy Resources (2008), the United States launched its first national nanotechnology initiative (NNI) in the year 2000. Following the creation of NNI in the year 2000, more than 60 nations have established their own national nanotechnology initiatives. In terms of investments amounts, the United States leads other countries by investing USD 3.7 B through its National Nanotechnology Initiative (NNI) followed by Japan with USD 750 M and European Union with USD 1.2 B in investment.

[5] Project on Emerging Nanotechnologies (PEN) was established in 2005.

[6] Lux Research was founded in 2004 as a spin-off of venture capital firm Lux Capital. Today Lux Research is fully independent; Lux Capital is a minority shareholder and the two firms have no operational links. Lux Research is a research and advisory firm that provides strategic advice and on-going intelligence for emerging technologies. They evaluate relevant technology applications in their industries, prioritize technologies, collaborators, and markets, continuously monitor innovators, competitors, and customers, connect with partnership or acquisition targets and tiny revenue streams in new and non-obvious markets. Lux Research analysts are a diverse mix of consulting professionals, market researchers, and Ph.D. scientists and engineers (Lux Research, 2008).

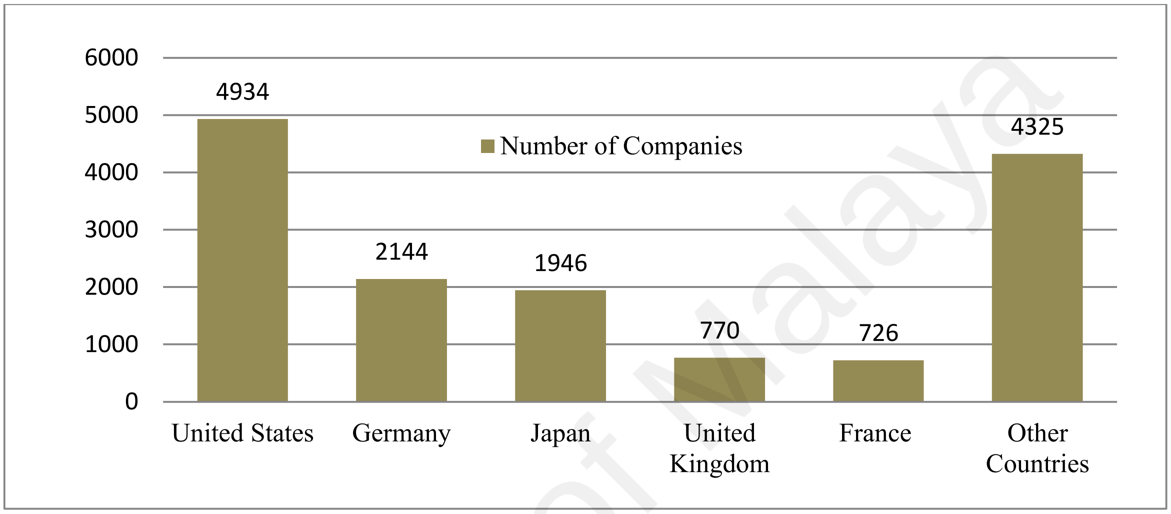
Bhatt (2005) provides a rough estimate of the number of companies focusing on nanotechnology related work worldwide currently, which is 550, including large companies that have opened up units devoted to this field, as well as start-ups and smaller companies. The Technology Transfer Centre (TTC) constructed the basis of Bhatt's rough estimate of 550, but did not account for the number of companies in the United States. According to the Technology Transfer Centre Report (TTC, 2007), there are over 300 nanotechnology companies in Europe, over a third of which are based in Germany (approximately 40%;) with a total of 120 companies, United Kingdom (approximately 23%) with a total of 70 companies, Switzerland (approximately 7%) with a total of 20 Companies, France (approximately 6%) with a total of 18 companies. The remaining 250 companies were from the Asia Pacific.

All firms measured by TTC comprised of a unification of nano product manufacturers, nano distributors, nano R&D laboratory based companies and mere subsidiaries of large manufacturing nano groups. The figure provided by various sources, also included non - manufacturers of nanotechnology. Therefore, this figure cannot serve as a viable measurement of what the actual number of companies involved directly in the area of nanotechnology really is. After a meticulous examination[7] of nanotechnology firms in Malaysia, there is an estimation of only two (2) nanotechnology SMEs firms. Based on the PEN Report, there are 1200 nanotechnology companies across United States. In negation to this statistic, according to the United Kingdom's Department of Trade and Industry (DTI)'s report on nanotechnology companies in 2010, and as shown in Figure 1.3, there are 4,934 nanotech companies in the United States (approximately 33%), followed by 2144

[7] by making physical visits to company sites

companies in Germany (approximately 14%), 1946 companies in Japan (approximately 13%), 770 companies in United Kingdom (approximately 5%), 726 companies in France (approximately 4%) and 4,325 companies across other countries (approximately 29%).

Figure 1.3 Total Number of Nanotechnology Companies Worldwide in Year 2010



Source: United Kingdom's Department of Trade and Industry (DTI), 2010

1.4 The Economies of Nanotechnology: Malaysia and Global

The United States launched the first national nanotechnology initiative (NNI) in the year 2000. Following the creation of its NNI in the year 2000, many nations have established their own national nanotechnology initiatives. The initiation of Malaysia's National Nanotechnology Initiative took place in the year 2006. Malaysia's NNI is a declaration of the government's pledge to sustain nanotechnology in this country. As clearly depicted in Figure 1.4, the United States, Western Europe, Japan are among the developed countries that have strengthened their R&D spending in nanotechnology research since 1997. In comparison, a cluster of Asian countries that form the Asian Nano Forum (ANF) is supported by 13 countries that include Australia, China, Hong Kong, India, Indonesia, Korea, Japan, Malaysia, New Zealand, Singapore, Taiwan, Thailand and Vietnam.

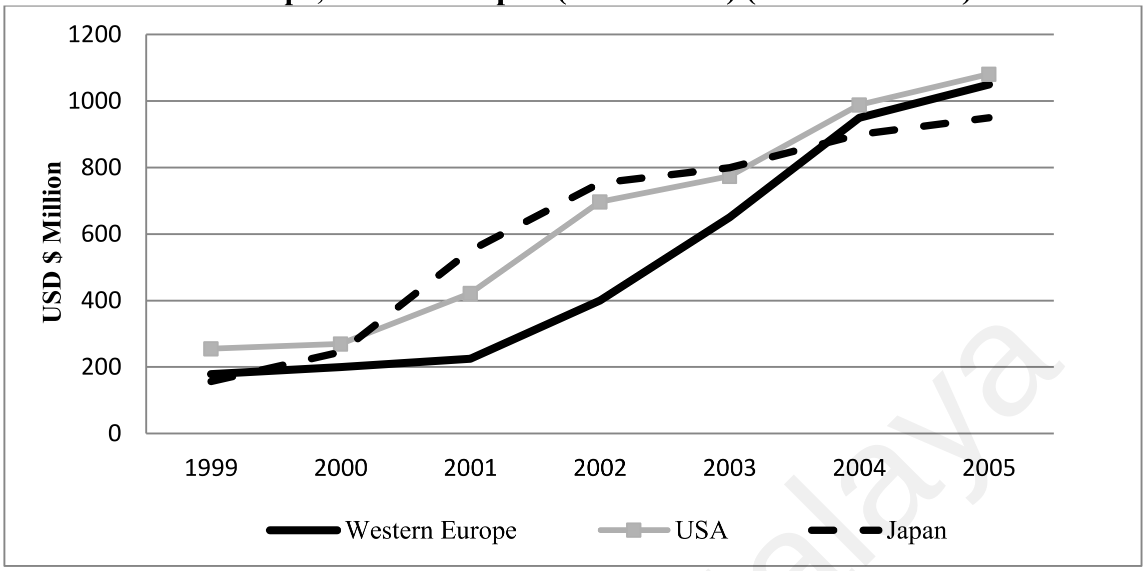
Narrowing to Asia Pacific, Japan, Taiwan and South Korea are deemed to be key contenders of the nanotechnology industry. In 2004, Japan invested a total of US$940 million for nanotechnology R&D, while South Korea and Taiwan invested a total of US$208 million and US$91.1 million respectively.

In comparison, Malaysia has invested a total of US$4 million in nanotechnology R&D. Malaysia is still lagging behind in R&D infrastructure and human resource development compared to other members of ANF. As Malaysia's counterpart from the South, Singapore has surpassed Malaysia with a total of US$9 million investment in nanotechnology R&D. Figure 1.5 shows each country's investment in nanotech R&D in the year 2004 and Figure 1.6 shows nanotechnology funding per capita in ANF Countries in Year 2004. By the end of 2008, governments in nanotechnology research (Cientifica, 2009) had invested nearly 40 billion. It was predicted that in 2009 alone, global government funding[8] for nanotechnology to hit US9.75B.

Motoyama and Eisler (2011) declare that international comparative data on nanotechnology investment is incomplete. However, based on my observation, there are no sources published after 2009 to validate this. Even though, there has been information on each country's spending on nanotechnology each year, there has not been any figures to state how these total spending have been distributed. Table 1.3 indicates that there is a vast difference of spending by countries, during a five (5) year planning investment in nanotechnology compared to investments made during a one (1) year planning period by several countries.

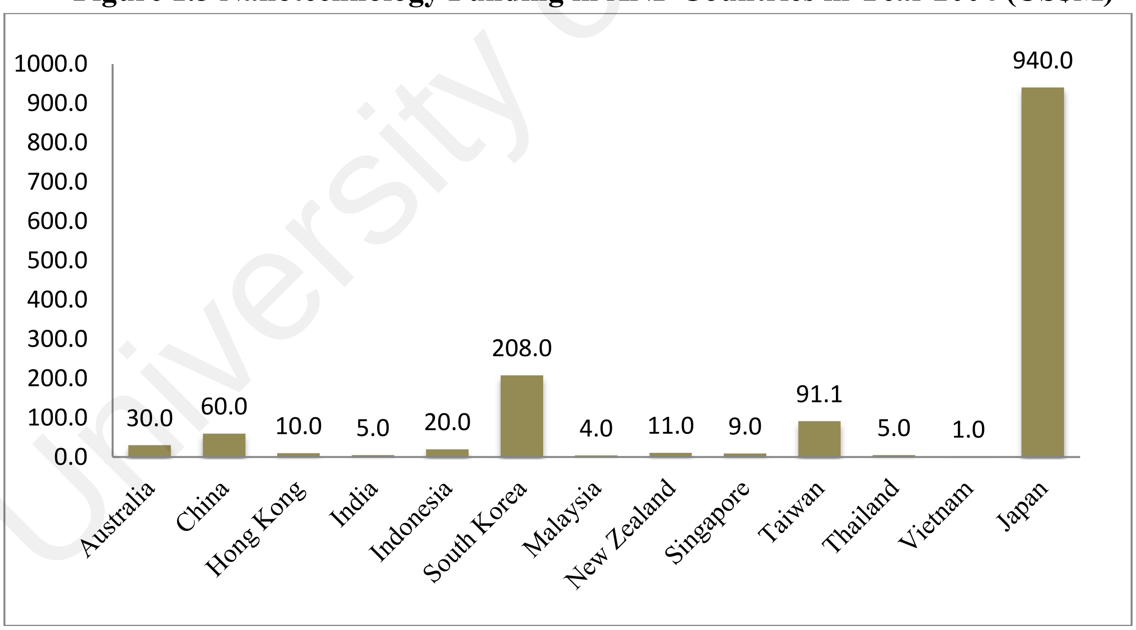
[8] The purpose of the money is to fund research and networking activities at universities, research centres and industrial research labs and related activities such as infrastructure, mobility and education of scientists, standardization and communication (Hullman, 2006). However, there is no data or evidence to prove how the total spending has been distributed.

Figure 1.4 Estimated Government Sponsored Nanotechnology R&D in Western Europe, USA and Japan (1999 – 2005) (in USD Million)



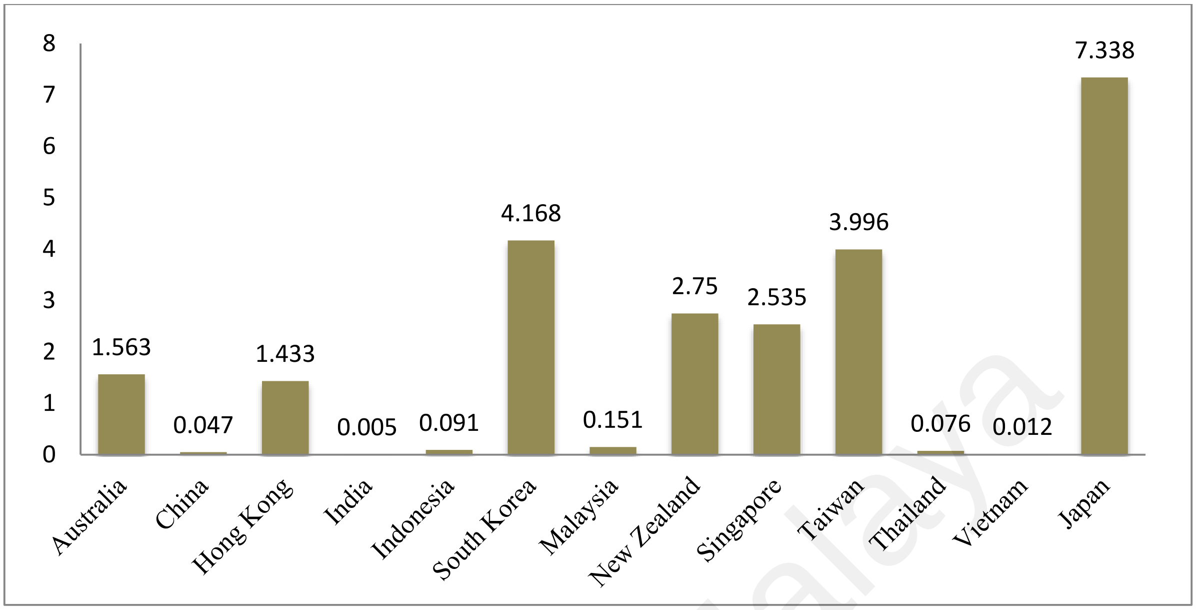
Source: Roco (2005) (Note: This is the most recent data available comparing Western Europe, USA and Japan together in terms of government sponsored nanotechnology R&D in the period of 7 years from the same author. Other sources was not used to extend the time series because measurement parameters and source data come from different statistical agencies)

Figure 1.5 Nanotechnology Funding in ANF Countries in Year 2004 (US$M)



Source: Asia Nano Forum (2004) (Note: This is the most recent available data comparing 13 countries including Malaysia in terms of nanotechnology funding since the Asian Nano Forum Summit which was held in the year 2005. Data available from 2005 – 2010 by ANF Summit in 2009 are funds Injected by the Government for Nanotechnology Development Based on Respective Planning Periods in Various Economies (2005 - 2010))

Figure 1.6 Nanotechnology Funding per Capita in ANF Countries in Year 2004



Source: Asia Nano Forum (2004) (Note: This is the most recent available data comparing 13 countries including Malaysia in terms of nanotechnology funding since the Asian Nano Forum Summit which was held in the year 2005. Data available from 2005 – 2010 by ANF Summit in 2009 are funds Injected by the Government for Nanotechnology Development Based on Respective Planning Periods in Various Economies (2005 - 2010))

Table 1.3 Funds Injected by the Government for Nanotechnology Development Based on Respective Planning Periods in Various Economies (2005 - 2010)

Country	Amount
USA via NNI	3.7 billion
European Union	1.2 billion

Source: MIGHT Report (Sept 2006)

Country	Amount
Japan	US $2.8 billion (2006 – 2010)
Taiwan	US $689 million (2009 – 2014)
Korea	US $259 million (2009)
China	US $62.5 million (2009)
Singapore	US $80 million (2009)
India	US $200 million (2009 – 2014)
Russia	US $5 billion (2008 – 2011)
Thailand	US $ 60 million (5 year plan)
Australia	US $ 100 million (5 year plan)
Iran	US $ 60 million (2008)
Vietnam	US $ 100 million (5 year plan)
New Zealand	US $ 13.8 million (2009)
Malaysia	US $35.26 million (2006 – 2010)

Source: ANF Summit Report (2009)

It can be observed that there has been lot of activities that have been conducted by various universities/institutes/CoEs to coxswain the advancement and sustainability of nanotechnology in our country. Efforts have been boosting but the level of progressive outputs has been slow paced, resulting in the sluggish rate of infiltration of nanotechnology prototypes - products into the commercial arena. Even way before the NNI was initiated; many of these universities/institutes/CoEs have been granted hefty amounts of dough to assist in translating lab prototypes into full-fledged products. Even so, there seems to have been a lack of any visible and massive impact coming from these endowments.

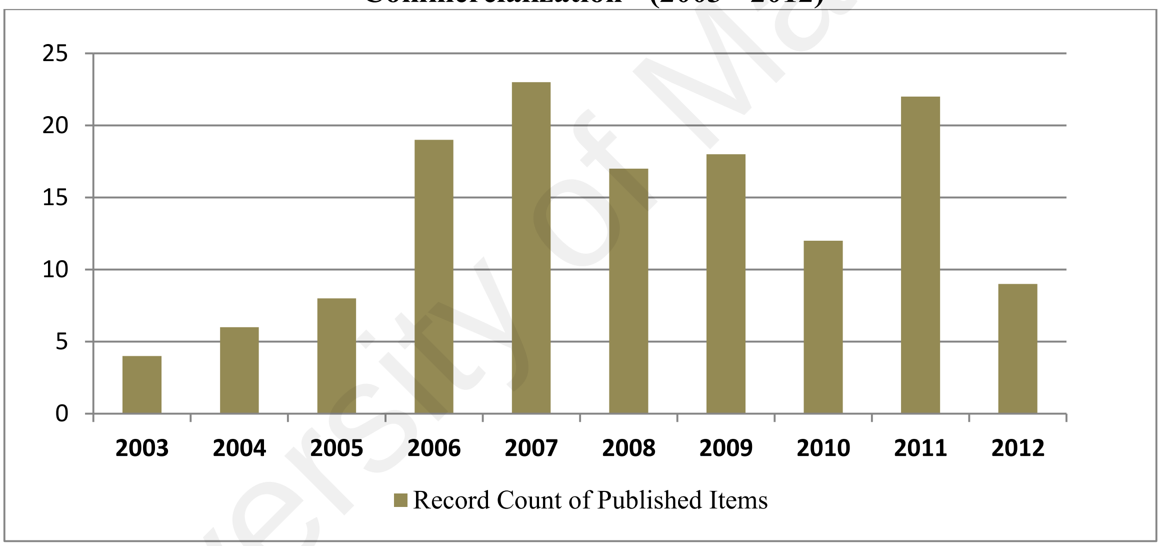
1.5 Research Problem

Nanotechnology is mostly developed in R&D laboratories in universities and research institutes. In addition to this, nano prototypes are not yet being widely translated to the country's commercial benefit, there are low number of researchers and allocated projects, low number of registered nanotechnology companies in Malaysia (0-2) and low number of publications. The Physics, Biology and Chemistry departments from various local universities are conducting nano lab research and experiments, but there have not been any significant outputs to reckon with till to date especially since the formation of NNI. This is because in addition to global competition by researchers and those seeking to produce nano related products and services, there have been critical barriers. These barriers limit the ability to capture the full potential of nanotechnology, including economic growth, wealth and job creation, and improvements in our standard of living and quality of life.

When the topic "Nanotechnology Commercialization" was searched through the Web of Science (WoS) (that covers the Science Citation Index Expanded (SCI-EXPANDED); Social Sciences Citation Index (SSCI); Arts & Humanities Citation Index (A&HCI);

Conference Proceedings Citation Index- Science (CPCI-S); Conference Proceedings Citation Index- Social Science & Humanities (CPCI-SSH)), during the period of 1980 to 2012, a total of 140 results showed up in the form of articles (81), proceedings papers (43), review (14), editorial material (7) and meetings abstract (2). Although the search was from 1980 until 2012, findings revealed that all 140 published items on the topic of "Nanotechnology Commercialization" were only published from year 2003 to 2012 (during the last 10 years and nothing before) as shown in Figure 1.7.

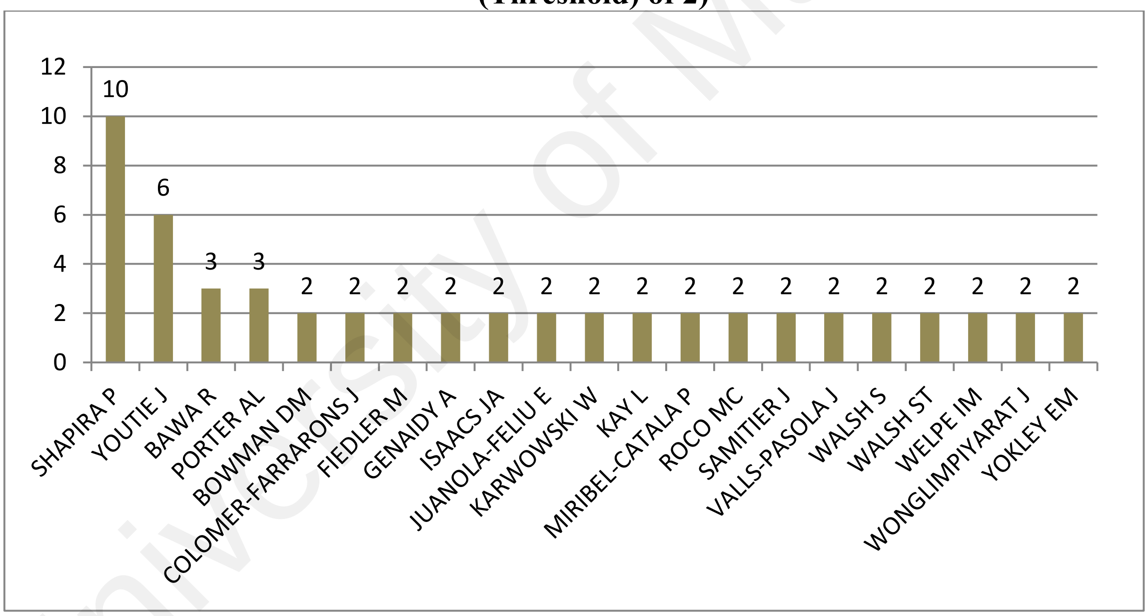
Figure 1.7 Record Count of Published Items in Web of Science on "Nanotechnology Commercialization" (2003 - 2012)



Source: Author's Illustration based on data extracted from Web of Science (WoS) (2012)

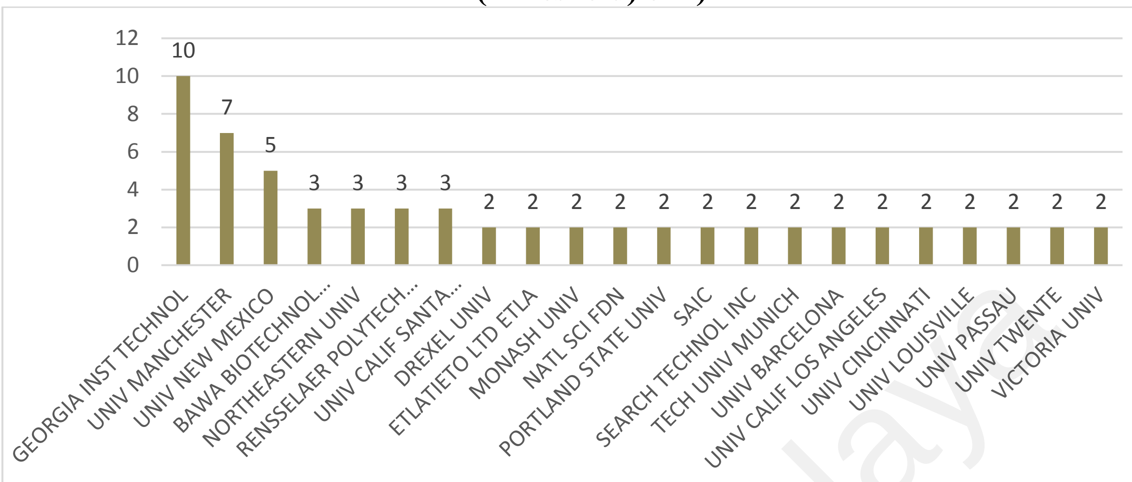
In terms of all 140 papers published in this topic, findings revealed that Philip Shapira published the maximum number of papers with ten (10) papers followed by Youtie, Bawar and Porter as shown in Figure 1.8. The rest of the authors had a minimum published record threshold count of between 1 and 2 that ultimately when added up sums up to a total of 140 published items. Findings as shown in Figure 1.9 also revealed that the maximum number of published papers came from Georgia Institute of Technology and followed by University of Manchester and University of New Mexico. The rest of the institutions had a minimum published record threshold count of between 1 and 2 that ultimately when added up sums up to a total of 140 published items. Except for few lines mentioned by Wonglimpiyarat's (2004) and (2005) of a not so detailed review of nanotechnology initiatives in Malaysia, none of the 140 global papers discussed the status of nanotechnology commercialization in Malaysia. Therefore, these findings reveal that there has been limited amount of research (almost none) focused on the commercialization of nanotechnology in Malaysia. Hence, this is one of the key stimuli to conduct this study.

Figure 1.8 Number of Published Items by Authors in Web of Science on "Nanotechnology Commercialization" (2003 - 2012) (with Minimum Record Count (Threshold) of 2)



Source: Author's Illustration based on data extracted from Web of Science (2012)

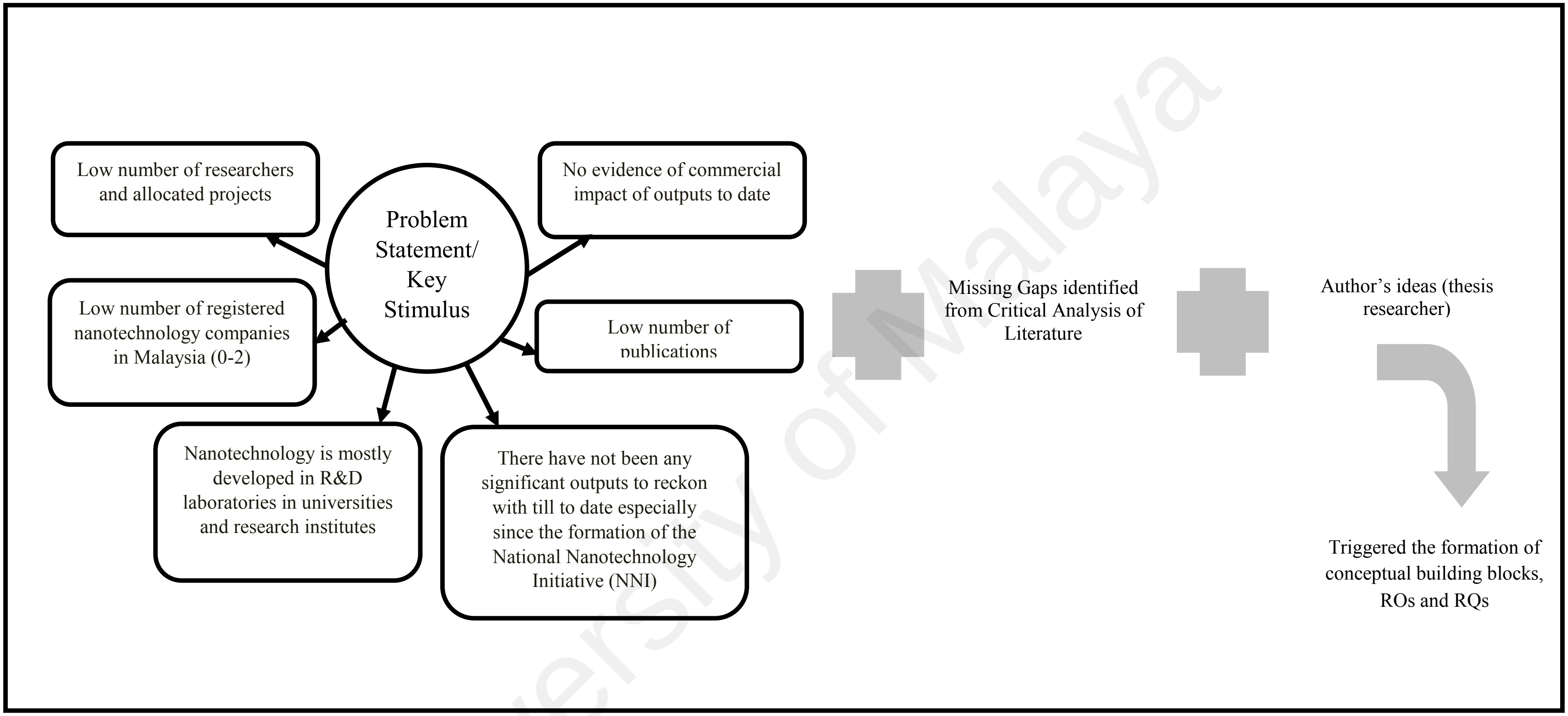
Figure 1.9 Number of Published Items by Institutions in Web of Science on "Nanotechnology Commercialization" (2003 - 2012) (with Minimum Record Count (Threshold) of 2)



Source: Author's Illustration based on data extracted from Web of Science (WoS) (2012)

Figure 1.10 shows the problem statement, and that missing gaps identified from literature were used to trigger the formation of building blocks, ROs and RQs for this study. The conceptual framework of building blocks is shown in Figure 4.1 of Chapter 4: Research Methodology.

Figure 1.10 Problem Statements



Source: Author's Design

1.6 Research Objectives

This thesis aims to:

i. Identify the barriers in the transition from research and development to commercialization of nanotechnology in Malaysia within the following three (3) dimensions:
    - The hybrid of comprehensive vs non-comprehensive education of nanotechnology
    - The distinct priorities of academia and industry and how it affects the R&D and commercialization of nanotechnology
    - The formation of R&D policy for nanotechnology

ii. Provide recommendations for policy and future studies for nanotechnology R&D and commercialisation in Malaysia.

In order to achieve the two (2) main objectives above, the study will examine the main issues pertaining to nanotechnology R&D and commercialisation through 14 main building blocks. Research questions pertaining to the study will be detailed in Chapter 4.

1.7 Significances of Study

The paramount reason why the subject of nanotechnology should be viewed as a critical aspect in the country's development agenda is due to the factual establishment that developed countries around the world have begun to forefront its research activities actively and rigorously during the past decade. These research activities have simultaneously received critical outbursts by pundits on the possible negative repercussions that may occur from its endeavours. In any emerging technology, outbursts as such is a usual phenomenon since it drives R&D activities through a multi-investigative route of rigorous safety and regulation standards and improvements in order to provide a justifiable and defensible motivation to the research community for its endeavours rather than suffering any future catastrophic losses. Developed countries that have pursued the nanotechnology revolution have identified its immense potential, and its lucrativeness has been linked to their nation's economic growth. Apart from associated linkages to economic growth, a principle of *caveat emptor* will be required to be emphasized to protect public health and safety, since it is understood that buyers are not experts of all the products they purchase. Over 1,300 nanotechnology products have entered the market, but are not widely known to the public because it is difficult to identify what percentage of these products is labelled as "nano". Nanotechnology, which has been linked to chemical weapons and defence, comes as a warning for possible destruction and devastation, and has cast a dark shadow on the better potentialities this technology has to offer. Therefore, research in nanotechnology continues in diversified aspects and the attempt to curb the limitations within nanotechnology product development is one of the research tasks. What is being emphasized here is that, negative research debates that follow in parallel with the evolvement of nanotechnology can only be controlled and curtailed when continuous research is performed on the subject. Hence, developing countries such as Malaysia should actively pursue nanotechnology development rigorously to innovate new ways how this technology can serve the nation's economic growth, in terms of its importance in each sector of its economy.

Considering that lot of investments have been made in the area of S&T, even though not specifically in the area of nanotechnology development and not many significant results attained, this study provides significant contributions in the form of:

i. To extract the key anomalies existing within the nanotechnology environment to give the government and policy makers reason to invest in developing solutions to restrict its bottlenecks.

ii. To indicate the urgency to prepare human capital in nanotechnology through education and training, for the fulfilment of nanotechnology relevant research activities in the next ten (10) years.

i. To make known the total cost of key infrastructure required to undertake a nanotechnology research activity in preparation for financial apportionments by potential applicants

ii. To clearly portray the parallel importance of patents and publications in universities, and its role in sustaining nanotechnology research.

iii. To provide the relativity and dependence of multidisciplinary subjects towards developing a future standalone nanotechnology educational program.

iv. To provide substantial reason for the government to assist universities in creating research opportunities in nanotechnology through partnerships.

v. To serve as a data specific and informative monologue in preparing an R&D policy for nanotechnology.

1.7.1 Contribution to Theory

After a thorough assessment in the diversified arrays of literature that may not be directly, but indirectly and loosely linked to nanotechnology R&D and commercialization, there has been insufficient emphasis on theory to provide grounds to accentuate the reasons for barriers between R&D and commercialization of nanotechnology. Especially in the absence of such critical studies towards this field in Malaysia, this thesis aims to provide sufficient information and theory to justify its objectives and provide future recommendations and policy directions in the context of the country's environmental setting.

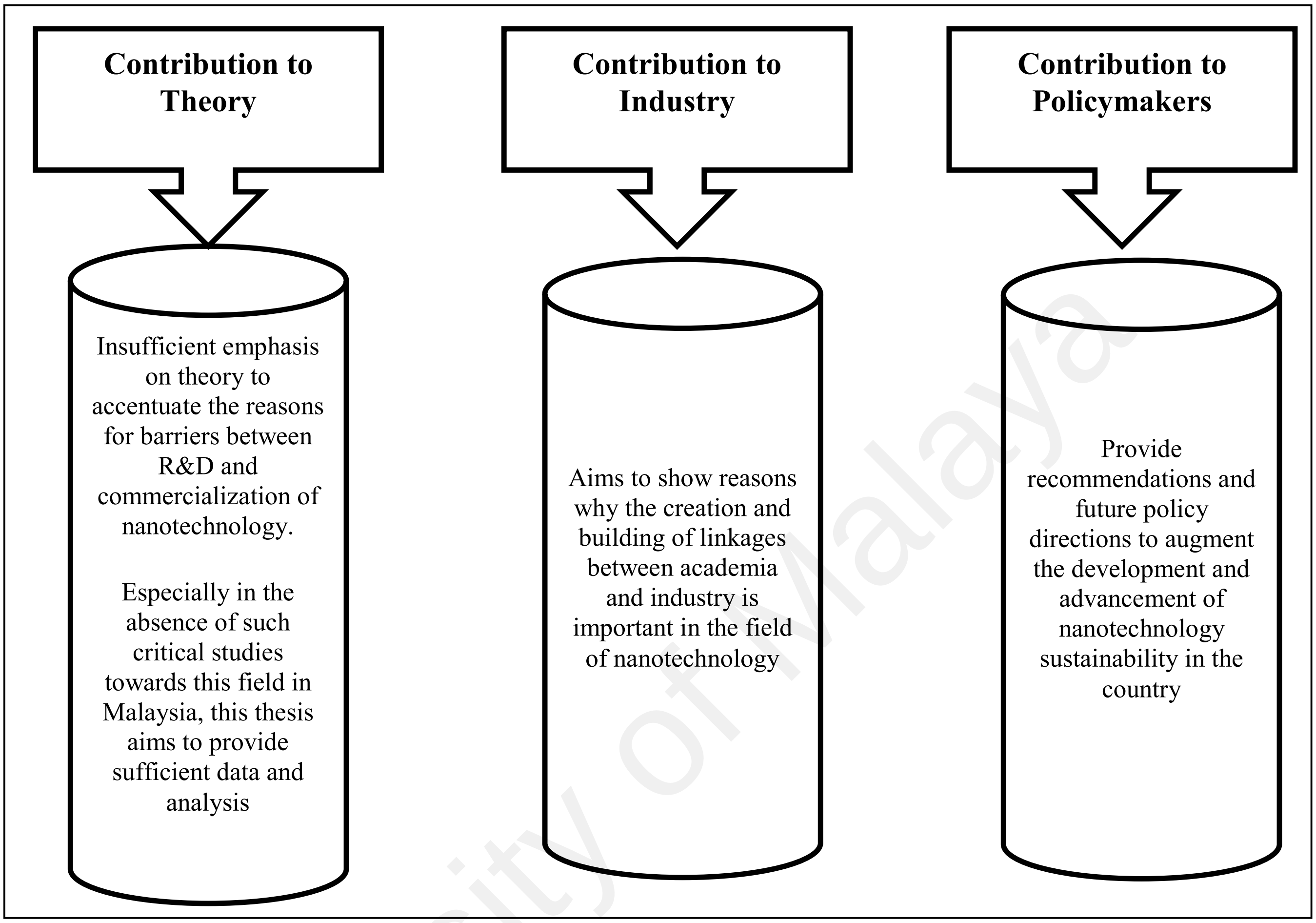
1.7.2 Contribution to Industry

This thesis aims to show reasons why the creation and building of linkages between academia and industry is important in the field of nanotechnology. This thesis justifies that U-I collaborative partnerships can ensure the sustainability of nanotechnology if only the channels through which both entities transport their individual capacities are executed through the recommendations discussed in this thesis.

1.7.3 Contribution to Policymakers

This thesis aims to provide recommendations and future policy directions to augment the development and advancement of nanotechnology sustainability in the country. Figure 1.11 indicates the contribution to theory, industry and policymakers illustratively through a cylindrical container layout.

Figure 1.11 Contribution to Theory, Industry and Policymakers



Source: Author's Design

1.8 Research Strategy

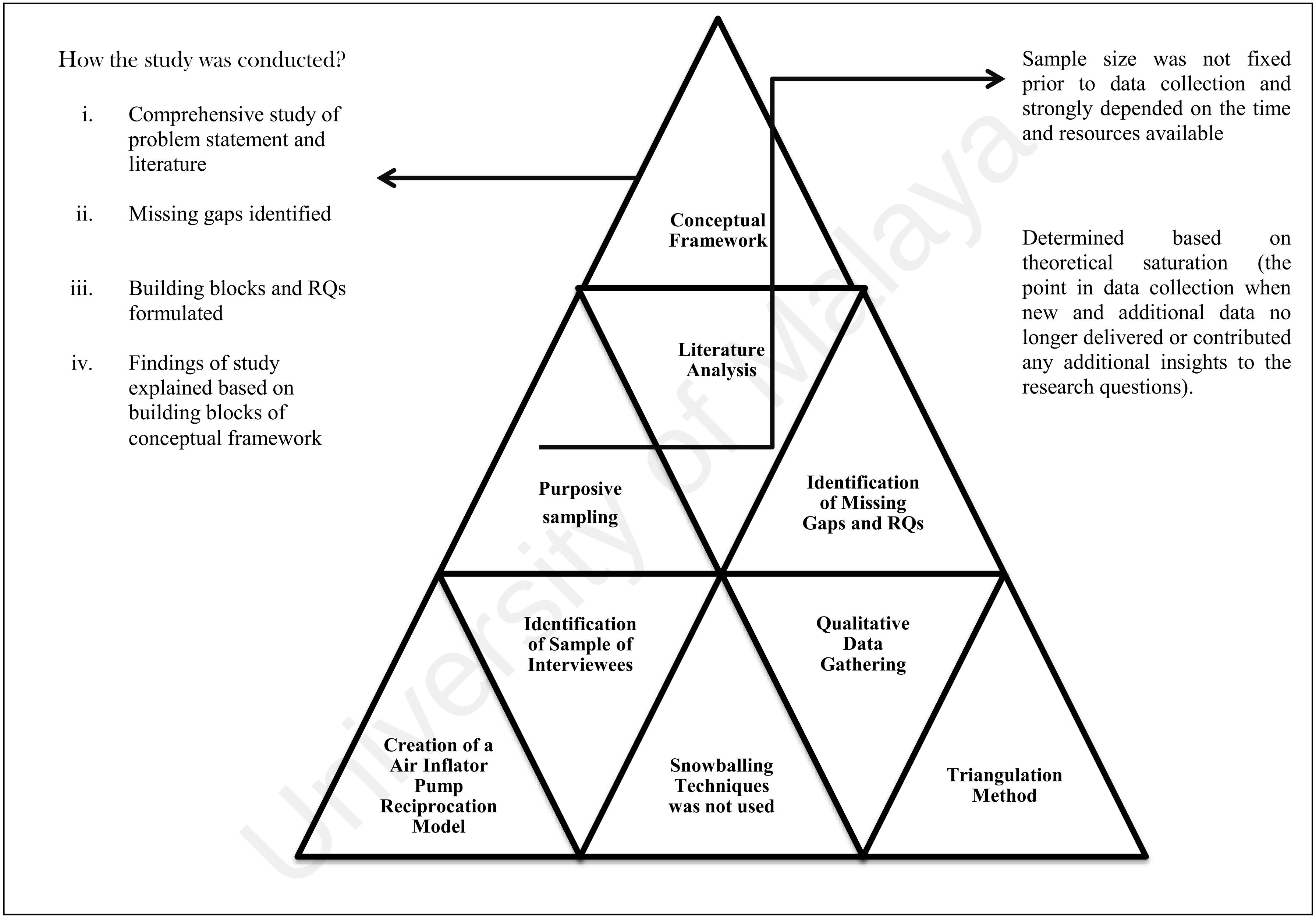
1.8.1 Review Pathway

As nanotechnology is the central theme of this study, it was important to demonstrate illustratively the flow from the original technology source into an innovation in order to definitely distinguish the terms like technology and innovation as two separate meanings since these two terms have been widely used within the text of this thesis. This was pertinent towards establishing to the reader at the beginning of the review in order to create a pathway towards understanding emerging technologies in terms of education, patent, publications, and product and process innovations. The chief idea was to depict illustratively, mainly through the researcher's very own design of various factors, which were distinctively identified through a series of time series analysis of core referred journals of many years. Citation analysis was conducted without the use of any software since the main element embedded within the core subject theme of each paper was not explicitly detected through title headings. Graphical diagrams were designed to prove the missing gaps associated to literature and how it was relevant to the construction of a conceptual framework and its associated building blocks.

1.8.2 Research Design

This section explains the design of the conceptual framework for this thesis through the formation of building blocks used as individual units of construction composed to formulate a larger subject entity that may interoperate with interdependent units of construction. Building blocks have been clearly labelled and a conceptual framework has been diagrammatically illustrated. This section also provides an explicit presentation of exploratory questions designed for this study and the researcher's very own research design model. Sampling method via purposive sampling and triangulation has been explained in terms of purpose, sampling size and methodology. Limitations that constrained the researcher and that which formed solid grounds in choosing a qualitative methodology instead of a quantitative approach in the process of generating findings for this study have been explained in Chapter 4 of this thesis. Figure 1.12 diagrammatically displays the thesis research design in brief in a segmented pyramid layout.

Figure 1.12 Research Strategy



Source: Author's Design

1.9 Lexis

Table 1.4 defines the terms according to the author's usage within the thesis text.

Table 1.4 Researcher's Definitions According to Thesis Text Usage

Terms	Researcher's Definitions According to Thesis Text Usage
Nanotechnology firm	A firm that has invested in a nanotechnology R&D lab, and is actively manufacturing nanotechnology products, for the purpose of marketing, distribution and sales.
R&D	The process of performing experimentation and problem solving using raw materials from basic research right up to creating newly designed applications during applied research for synergizing functional nano prototypes prior to manufacturing and production.
Commercialization	The process of marketing, distribution and sales (after manufacturing and production) of fully-fledged products for profit-making benefit and successful exploitation by companies and individual consumers. Commercialization of R&D outputs is also taking place in the forms of licensing, materials transfers, spin out companies, developing prototype/pilot plant for companies, and transfer of know how either through agreement signed or knowledge transfer programme. Types of services that universities offers to industry are consultancies, contract research and testing services.

1.10 Thesis Configuration

This thesis consist of six (6) chapters and is structured as follows: Chapter 1 introduces nanotechnology in brief, the economics of nanotechnology with regards to industries, firms and products, research problem, research objectives and the significances of study and research strategy in brief. Chapter 2 provides a critical review on the nanotechnology R&D and commercialization literatures in a time series basis. Chapter 3 presents the current status of nanotechnology in Malaysia and Chapter 4 presents the research design and methodology. Chapter 5 presents the research findings and Chapter 6 provides an in-depth discussion based on the findings, recommendations for improvement, further research and conclusion.

1.11 Summary

This chapter while providing a comprehensive view of the background of nanotechnology from the perspective of nanotechnology industries, firms, products, economies, main problem statement and research objectives, continues to pave way to a time series analysis of nanotechnology literature on nanotechnology in Chapter 2.

CHAPTER 2: Literature Review

2.1 Introduction

This chapter provides a critical review on the literature on nanotechnology R&D and commercialisation. The chapter comprises of six (6) main sections. Section 1 highlights the significance of emerging technologies and how these technologies served as an underlying root source of thriving innovations today by meticulously creating a comprehensible distinction between the two terms. This section also diagrammatically demonstrates the linkage between emerging technology and innovation within the various stages of R&D and commercialization. Section 2 provides a chronological overview of the emergence of nanotechnology. Section 3 provides a state of the art review of nanotechnology education and training; uprooting multiple factors that contribute to the production of human capital for R&D and commercialization of nanotechnology. Section 4 provides a thorough state of the review of nanotechnology patents and publications. Section 5 and Section 6 highlights the product and process innovations and existing nanotechnology policy in various economies. The following missing gaps in three (3) main dimensions, identified through the review of literature are as follows:

I: The hybrid of comprehensive vs non-comprehensive education of nanotechnology

II: The distinct priorities of academia and industry and how it affects the R&D and commercialization of nanotechnology

III: The formation of R&D policy for nanotechnology

2.2 Innovations in Emerging Technologies

Multiple technologies have surfaced into becoming transforming agents or catalysts responsible in the development of products and processes that can augment the economic growth of a nation. The main conception is for these technologies to serve as a value-adding entrenchment within the already existing products and processes, throughout the various stages of R&D, manufacturing and production. All these form part of the progressive medium of innovation. These technologies also have created an impact on the services offered by firms. Albeit many benefits that have resulted from these technologies, however, Hung and Chu (2006) clearly points out that these emerging technologies have not yet demonstrated potential for changing the basis of business competition. Offshoots innovations from emerging technologies include spin transistors, gene therapy, interactivity and e-commerce, intelligent sensors, digital imaging, micro machines, Magnetic Resonance Imaging (MRI) and plasma fusion reactors. These innovations are only scientific research based innovations, which were the result of emerging technologies. The technology[9] is the original source of these innovations[10]. Without the existence of these technology sources, these innovations would not have come to exist. Table 2.1 shows a list of offshoot innovations and its corresponding emerging technologies. Of all these emerging technologies, Fleisher, et al (2005) heralds nanotechnology, as the most prominent emerging technology, as they are the key technologies for the 21st century.

Boyack, et al (2014) underscore two (2) new properties, which are "noticeability" and "unexpectedness", associated to the term emergence" and among the various un-universal definitions available for the term "emergence", the commonality almost mutually agreed is "newness" and "growth". Further sections will explicate on the subject of nanotechnology. Breitzman and Thomas (2014) state that it is a challenging task to identify, which technologies are emerging and, which has already emerged. Therefore, through an

[9] Technology is a replicable artefact with practical applications and the knowledge that enables it to be developed and utilized. Technology is manifested in new product, processes, systems, including the knowledge and capabilities needed to deliver functionality that is reproducible (Dodgson, David and Salter, 2008). Innovation is the creation of a new idea and its reduction to practice – in the form of an outcome, a new product, process or service or a process of managerial and organizational combinations and decisions. Essentially, innovation is the successful commercial exploitation of a new idea. It includes the scientific, technological, organizational, financial and business activities leading to the commercial introduction of a new (or improved) product or service (Dodgson, David and Salter, 2008).

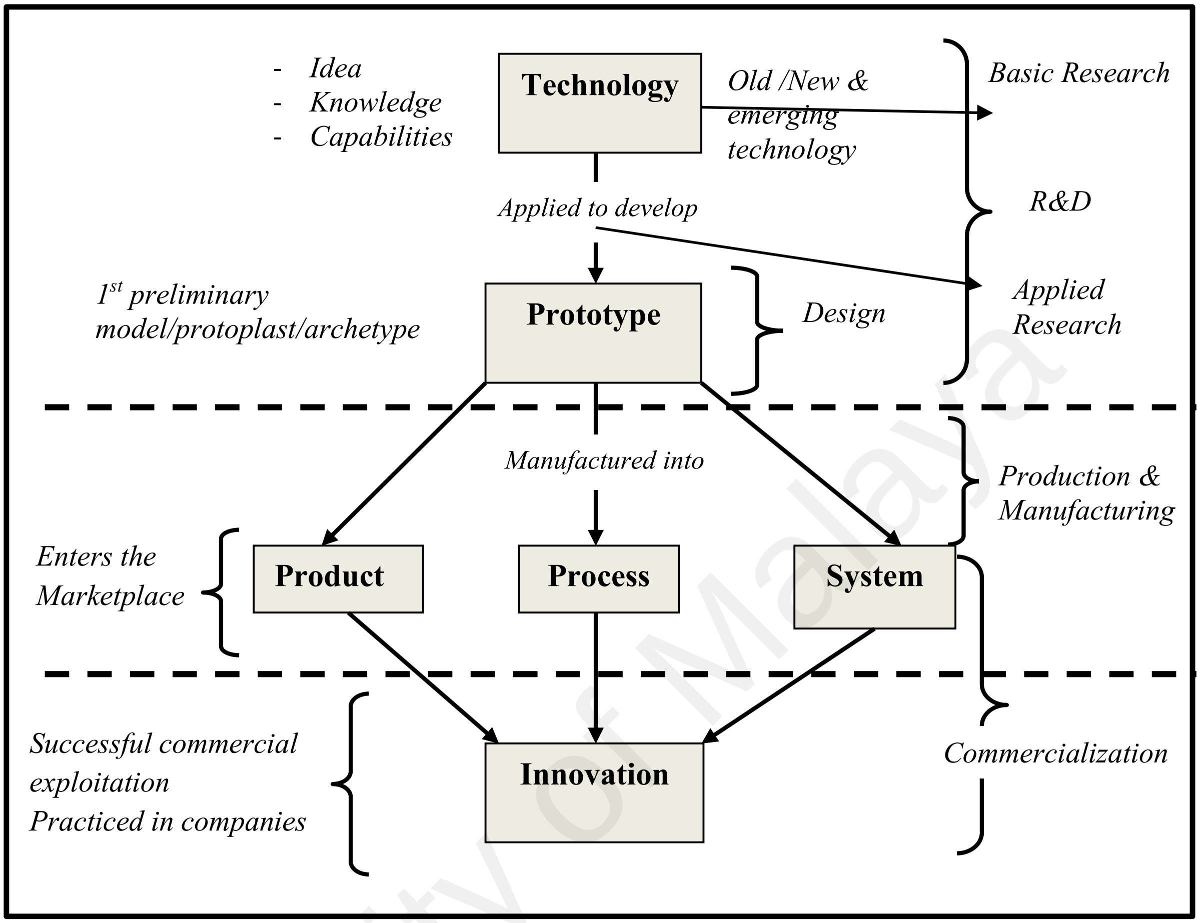
Emerging Clusters Model, that which applies patent citation techniques, Breitzman and Thomas (2014) identified that patents found inside the emerging clusters have an higher than expected impact on technology developments compared to patents falling outside the emerging clusters, which have a lesser expected impact on technological developments. Figure 2.1 illustrates the conversion process from the application of an emerging technology into the development of a prototype, later designed and manufactured into a product and finally into an innovation.

Table 2.1 Innovations Derived from Emerging Technology Sources

Innovations	Emerging Technology Sources
Spin Transistors	Spintronic
Gene Therapy	Genetic technology
Interactivity and E- Commerce	Information Technology
Intelligent Sensors	Micro Electromechanical Systems (MEMS) and Nano Electromechanical Systems (NEMS) Technology
Digital Imaging	Digital Technology
Micromachines	Micro Electromechanical Systems (MEMS) Technology
MRI, Plasma fusion reactors, nuclear magnetic resonance	Superconductivity

Source: Wilson et al (2002), Kumar (2008), Pradeep (2008) Binns (2010) and Timp (1999)

Figure 2.1 From Roots of Emerging Technologies to the Branches of Innovations



Source: Author's Design

2.3 The Emergence of Nanotechnology: A Timeline

There has been a serious misconception that nanotechnology is only now becoming the next big industry after information technology, biotechnology and the convergence of the two, which is the bioinformatics[11] revolution. Many experts and scholars, regard nanotechnology as the fourth industrial revolution (Chih et al, 2012). Nanotechnology is in fact, built on a long history of technologies much older than is widely believed and other than researchers; only a handful is familiar of its existence. In 2004, North Carolina State University conducted a telephone survey of 1,536 adults and found that 80% of the respondents knew little or nothing about nanotechnology (Austin, 2004). The following year, in 2005, according to the University Texas Pan American (UTPA), the percentage of respondents from 978 students, who knew what nanotechnology was, was only 17% (Sheetz et al, 2005). Nevertheless, nanotechnology products have been in the commercial market for centuries. The first product based on "bottom-up" nano-properties of a material was carbon black (Romig et al, 2007). Many researchers have described nanotechnology as an "emerging industry" even though they are conscious that it has been around long before our time. This is why Romig, et al (2007) question policy makers as to: *'why do we see these technologies as "emergent"?'* when they actually are not. The existing verities simply reaffirms that nanotechnology should no longer be hailed as an embryonic (emerging) technology, but to be referred to as a mature (established) technology, which have derived many beneficial products and innovations, which are far lighter, faster, cheaper and safer, weighed against what was existing before. As opposed to Hung and Chu

[11] Even though nanotechnology and biotechnology show evidence of analogous technology evolutionary patterns (Rotharmel and Thursby, 2007), it is nanotechnology that has the absolute potential to impact a wider array of industry sectors than biotechnology (Youtie et al, 2008; Juanola-Feliu et al, 2012) especially those with higher than average R&D intensity (Juanola-Feliu, et al, 2012). Examples of convergence technologies include molecular machines comparable to the natural machinery inside living cells, medical devices and materials that might be implanted inside the human body, and the application of principles from computerized natural language processing to genomics and proteomics (Roco and Bainbridge, 2002).

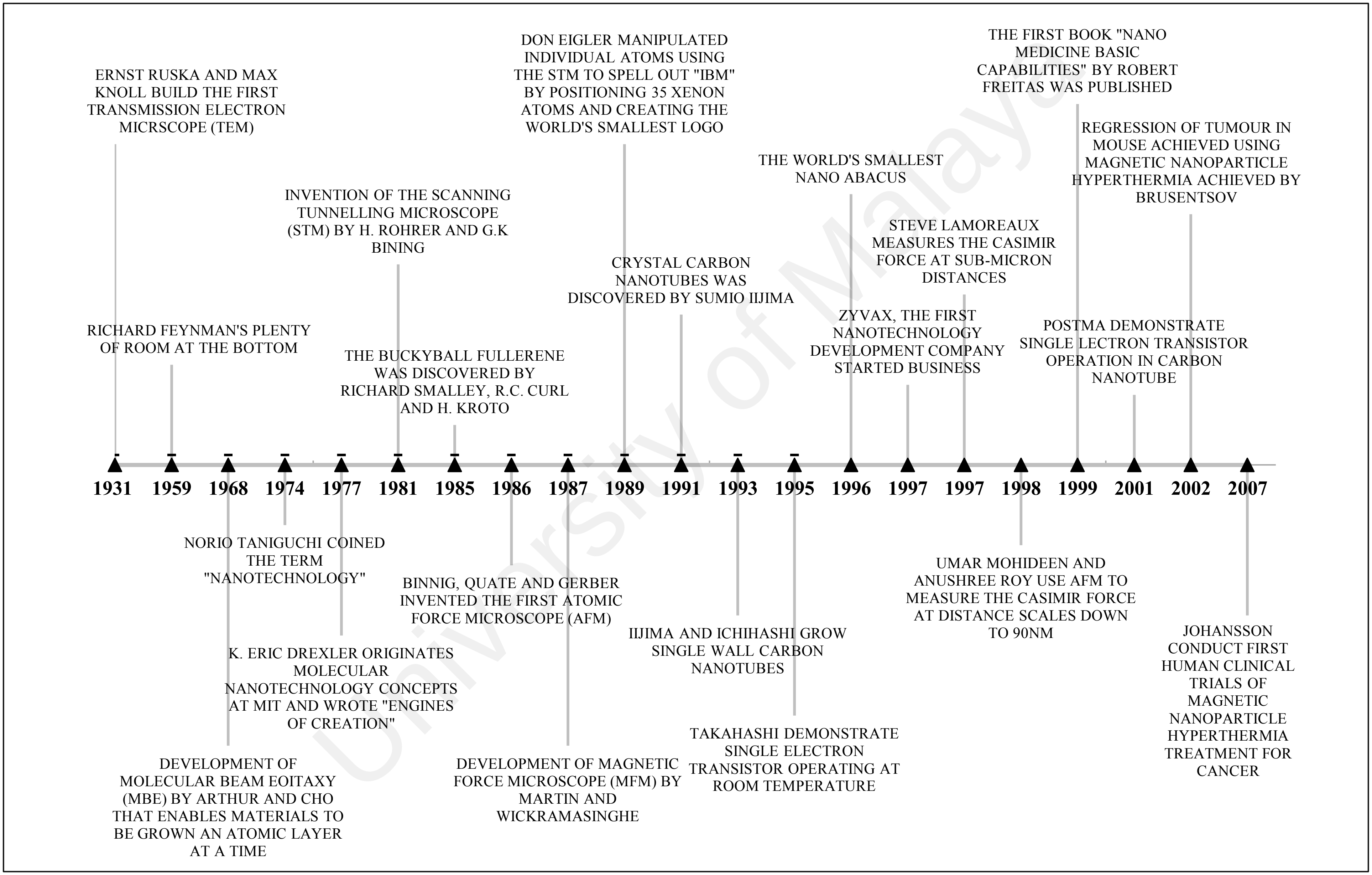
(2006), Romig, et al (2007) states, that nanotechnology has demonstrated itself as an unyielding potential catalyst in altering the basis of competition.

As indicated in Figure 2.2, Professor Richard Feynman[12] enunciated nanotechnology on 29 December 1959 who described molecular machines building with atomic precision in his talk entitled *"There is a plenty of room at the bottom"*. Feynman, the Nobel Prize Winner in Physics did not use the exact term nanotechnology, but accurately described its potential for extreme miniaturization and the self-organizing and self-assembly of molecules. Professor Norio Taniguichi then introduced the term 'nanotechnology', in 1974. Taniguichi used the term to describe the ultra-fine machining, which is the processing of material to nanoscale precision. In 1977, K. Eric Drexler[13] derived molecular nanotechnology concepts at MIT based on bottom up molecular manufacture, popularized in his book "Engines of Creation", which was published in 1986. Drexler in the Proceedings of the National Academy of Sciences, USA published the first technical paper on nanotechnology, in 1981. Later, the world welcomed the arrival of the Scanning Tunnelling Microscope (STM) by IBM Researchers H. Rohrer and G.K. Binning in 1981, the discovery of the bucky-ball (fullerene) in 1985, the atomic force microscope in 1986 and crystal carbon nano tubes was discovered in 1991. In 1993, Iijima and Ichihashi grew single wall carbon nanotubes, whereas in 1995, Takahashi demonstrated single electron transistors operating at room temperature. The world's smallest nano abacus was created in 1996, whereas in 1997, Zyvax became the first nanotechnology development company. In 1997 and 1998, Steve Lamoreaux measured the Casimir force at sub-micron distances, and Umar Mohideen and Anushree Roy used the Atomic Force Microscope (AFM) to measure the Casimir force at

[12] Feynman discussed nanotechnology from the *technical* perspective (Mangematin and Walsh, 2012)
[13] Drexler discussed nanotechnology from the *commercial* perspective (Mangematin and Walsh, 2012)

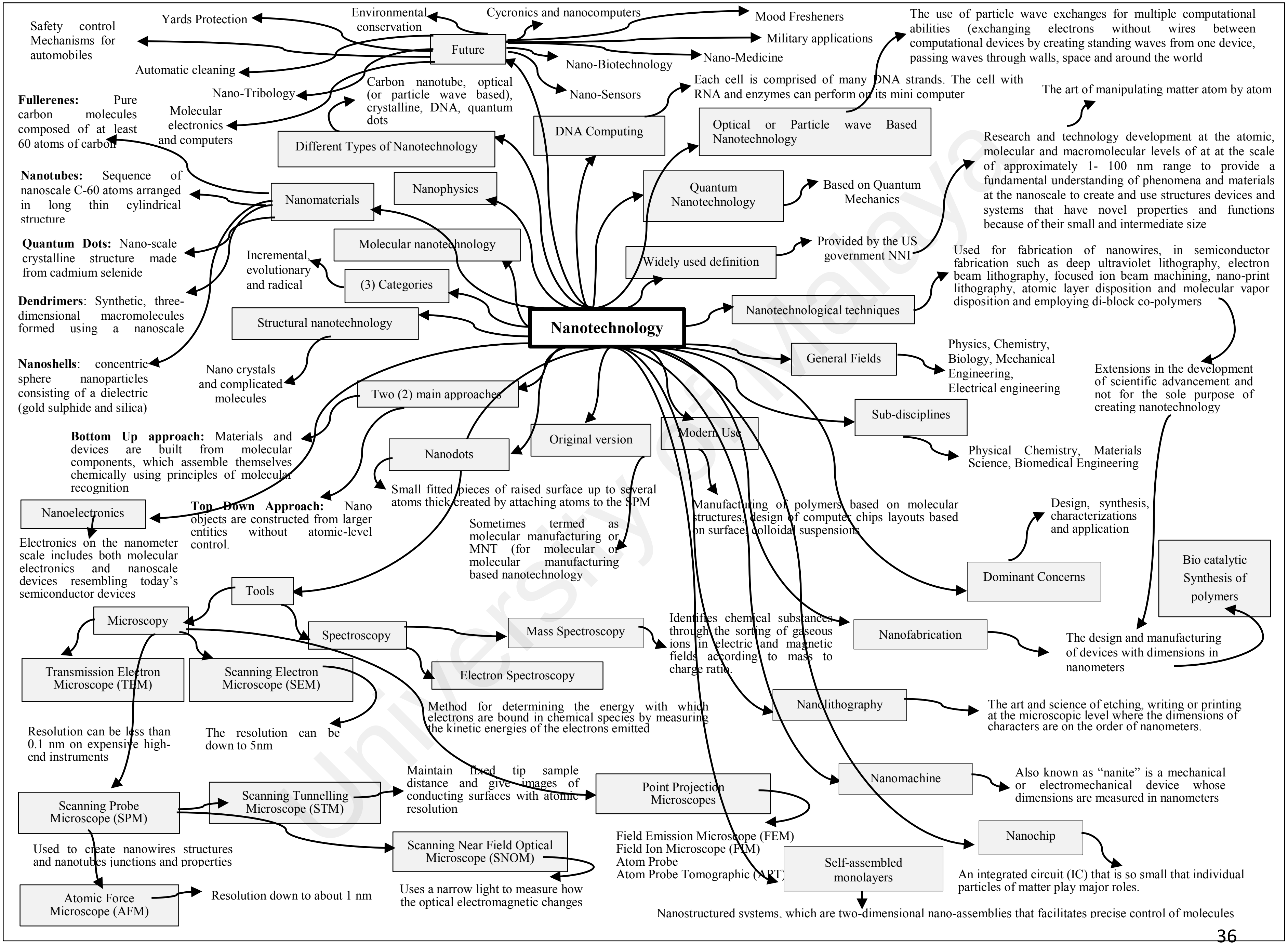
distance scales down to 90 nm. In 1999, Robert Freitas published the first book on nanotechnology entitled “Nano Medicine Basic Capabilities”. In 2001, Postma demonstrated single electron transistor operation in carbon nanotubes and in 2002, Brusentsov through the use of magnetic nanoparticle hyperthermia achieved a regression of tumour in mouse and in line with this, five (5) years later, in 2007, Johansson conducted the first human clinical trial of magnetic nanoparticle hyperthermia treatment for cancer. In continuance of this section, Figure 2.3 provides a mapping of nanotechnology for an astute understanding of its connecting branches of science.

Figure 2.2 Nanotechnology Timeline (1931-2007)



Source: Author's Illustration based on Kumar (2008) and Binns (2010)

Figure 2.3 Mapping of Nanotechnology



Source: Author's Design Map based on key descriptions of Wilson et al (2002), Kumar (2008), Pradeep (2008) Binns (2010) and Timp (1999)

2.4 Nanotechnology Education and Training: Knowledge Bearing Assets in the Commercialization Process

The intrinsic worth of nanotechnology is rapidly intensifying and presenting its value in nigh on all sectors of the economy. Existing nano knowledge workers from these sectors have already embarked on a mission to emanate and unveil its hidden potential, as well as its adverse effects from the inner to the outward surface, for the betterment of humanity. Yet, only a handful is familiar of its existence. The state of the art review of literature in this section clearly proves that university researchers and students are the knowledge bearing assets required during the invention or discovery stage and prototyping or testing stage within the R&D process. As researchers understand it, there is an absolute need for a skilled and educated workforce, trained at diversified levels, associated to this field, in order to meet the projected demand in the future. Thus, this section of the thesis studies and analyses the current state of the art of nanotechnology from the perspective of education and training; through a chronological and time series flow of selected core referred journals, published in the area of nanotechnology education and training.

2.4.1 Demand Pull and Supply Generation

Fonash (2001) underscores the challenge of creating a pool of students pursuing nanotechnology education, and the need to supply pertinent and suitable programs to cater the demand of the scientific engineering technical workforce that have to embark from secondary school. Fonash (2001) does not imply, that there is already an existing demand, but emphasizes that there should be a broad array of educational programs designed to inflame the young minds in the area of nanotechnology. In order for this to happen, these educational programs need to articulate the future prospects and expectations to students who enrol into such programs. Even though this field has existed for almost a decade, it silently remains a new frontier, whose unknown possibilities and paths are paving towards more advance explorative opportunities, by who else, but the new and young wits. This is attainable when there is an abundant pool of students, geared towards becoming the future nanotechnology workforce. The effect of nanotechnology education has to be magnetic enough to pull students into this field. Looking at the trifling number of students worldwide, involved in anything that is even tenuously close or related to aspects of nano, a "careful and vigilant design" of this course is paramount and urgently required. Uddin and Chowdhury (2001) have generally suggested interactive learning, both inside and outside the classroom, with no reference to any particular environment.

Logically, this form of two way learning can only occur between student and the subject matter experts. Subject matter expertise can be delivered through the internet, in the form of software or through interactive lectures where the instructor gets students to participate in an activity that allows them to work directly with the material at hand. To some extent, some refer interactive learning to 'hands on training'. Nevertheless, it is important to note that 'hands on training' constitutes only a small segment of interactive learning; whereby interactive learning requires the involvement of various actors from various environments, by which information could be shared and transferred from one actor to another, through a continuous process. If this is successful in the case of nanotechnology, then interactive learning has triggered knowledge transfer and has generated knowledge accumulation, both inside and outside the classroom.

With regard to undergraduate programs, even if it is not a nanotechnology specific course, Uddin and Chowdhury (2001) have recommended educators to introduce the concept of nanotechnology during the freshman and sophomore engineering courses and to continue this course offering throughout the subsequent engineering science curriculum. Within the same theme but in a different line of argument, Roco (2002) had proposed instilling nanoscale concepts, as early as kindergarten right up to continuing education, for retraining purposes and that these endeavours should be made to institutionalize nanotechnology, within K-12 education and higher academic institutions.

Nevertheless, it is plausible to expose students to this concept during the freshman and sophomore engineering courses, as suggested by Uddin and Chowdhury (2001), but is highly improbable for it to take effect at K-12 level. Hence, at this point of time, this attempt as suggested by Roco (2002) is a challenging feat. Adding to this proposition, Roco (2002) suggests emphasizing interdisciplinary internships in graduate programs, whereas Meyyappan (2004) proposes that these nanotechnology internships should select highly skilled high school and undergraduate students, as a way for these programs to attract young students to stay interested in science and engineering in addition, to pursue a career in research. Meyyappan (2004) also addresses the importance of offering elective courses in nanotechnology to senior undergraduate students. The point made by Meyyappan (2004) is definitely convincing. Nonetheless, four years prior to Meyyappan (2004), Corbett, et al (2000) states that only concentrated multidisciplinary undergraduate and postgraduate courses will be able to develop these indispensable and advanced skills within this intensive science based area. Cozzens (2012) stresses that since emerging technologies are science oriented; they demand higher skill levels in production-based processes and because they necessitate resources and outlays, they frequently sell at high prices. Nevertheless, certain major universities, who have self-motivated and dynamic faculties, engaged in nanotechnology research, will be able to perform this task. Evidently, those who do not have an active faculty will fall behind. Hence, Meyyappan (2004) stresses the importance of extending these opportunities to non – research colleges and universities, who are not actively engaged in nanotechnology through the professional scientists or engineers cum academics, who teach at these institutions, via strategic partnerships and through distant learning.

In fact Chang, Fan, Yang (2004) are in the same view of Meyyappan (2004), as they suggests that strategic partnerships with surrounding universities should alliance with local industries and other research organizations, to jointly develop teaching courses and technical specialties. In order for strategic partnerships to be triumphant, research universities firstly need to articulate distinctively, what competitive (the 'gung –ho') value they want to bring into the relationship in terms of nanotechnology, and what universities are prepared (and not prepared) to give up, because every partnership involves loss of independence. It is important that key actors who are going to be involved with any decision related to the subject of nanotechnology, agrees to key objectives and has realistic expectations.

Merkerk & Lente (2005) stress that considering that nanotechnology remains at the nascent platforms of its development, co-construction by all associated actors within the innovation system is not visibly direct and straightforward. Roelofsen, Wouter, Kloet & Broerse (2011) concludes that private – public research consortia increasingly have to communicatively transact with a heterogeneous stakeholder network (different actors within the consortia) and through multiple stakeholder dialogues, with a special focus on learning between stakeholders, has the potential to form a conduit between research and practice. This solitary requirement itself can cause many breakdowns among alliances, while at the same time jeopardizing previous financial investments and endeavours. Nevertheless, Leung (2013) interestingly points out, that, when two or more actors are connected through a collaborative, yet distributive network, the dispersal of benefits is unhinged; whereby one member of the network may profit advantageously more than the other, and stresses on the study by Smith-Doerr (2005) that benefits will be only be felt by certain members of the network. Motoyama (2014) stresses on the studies of Becker et al (2006), Niosi et al (2006), Sampath et al (2006) and Breztniz et al (2011) and emphasize that despite efforts made to strengthen collaborative ties between industries and universities, research has clearly demonstrated an explicit focus on patenting, publications, spinoffs and licensing. Motoyama (2014) highlights the studies of Kline and Rosenberg (1996) and Cohen et al (1994), by reiterating, that traditional collaborative measure between University – Industry (U-I), known as the "linear model", whereby the university is fully absorbed into the processes of knowledge creation, generation and basic research, opposite to that of applied research processes and commercialization practices (typically immersed by industry) is constantly challenged by scholars who prefer the integration of innovative research processes through dialogue and consulting between the conduit of University – Industry (U-I).

Dunkley (2004) affirms that the demand for study in particular fields, would shift from one discipline to another, due to job growth in diversified work sectors, due to nanotechnology.

Nevertheless, it holds the potential to reshape intellectual life, since college enrolments will change due to the introduction of new types of jobs. Stephen, Black, & Chang (2007) in their study conclude that the job market for those with skills in nanotechnology still remains small, where the largest part of the growth, is centered at universities and government labs. The authors, also further point out that in terms of supply, the pipeline is filled through the Principle Investigator's (PI) approach, having students attached to one's faculty member's lab rather than a formal program; whilst concurring with Vogel & Campbell (2002) that nanotechnology is "too young" to exist as a standalone program. Six years after, Noella (2011) states that nanotechnology jobs are not restricted to R&D labs anymore, but encompassing a broader set of activities in manufacturing and marketing.

According to Mongillo (2007), scores of jobs will be required to fill in the vacancies for nanotechnology. Four years prior to the study conducted by Stephen, Black, & Chang (2007), Roco (2003) affirmed that nanotechnology job projections were estimated to reach to nearly two (2) million workers worldwide by the year 2014. These jobs will arise in countries like the USA (0.8-0.9 million), Japan (0.5-0.6 million), Europe (0.3 – 0.4 million), Asia Pacific (0.2 million) and other regions (0.1 million). Twenty (20) percent of two (2) million nanotechnology workers required by year 2014 expected are to be scientists, with the remaining 80 percent to be consisting of highly skilled engineers, technicians, business leaders and economists. In addition to this, Roco (2003) has estimated that nanotechnology will generate another five (5) million jobs worldwide, in supporting fields and industries, and the spawning start-ups will take place within the next ten (10) to fifteen (15) years. On even a more positive upbeat, Lux Research (2004) anticipates a number of ten (10) million manufacturing jobs related to nanotechnology will be created by

2014. This is far from the prediction and expectation of Roco (2003). Hullmann (2007) argues that many of these jobs will be created within SMEs, but not exclusively. However, the findings from the Malsch & Oud (2004)'s Open Consultation on the European Strategy for Nanotechnology, the lack of highly skilled staff would be the main difficulty for SMEs and start-ups in nanotechnology. The National Science Foundation (NSF), has hailed for the calling for children between the ages ten (10) and seventeen (17) to be educated now about the field in order to define the job market later, as adults. As Roco (2002) points out, as nanotechnology, moves into mainstream, companies building products at the atomic level, eventually will face a staid scarcity of talent – far worse than what is actually occurring.

Albeit, there is a prediction for greater demand for nanotechnology workers for the future. Uldrich (2005) claims that only a few states in the US have staidly addressed the issue of workforce development in the area of nanotechnology. Speaking of the necessity of steering demand and supply in nanotechnology, Ernst (2009) suggests contemporary approaches and practices, such as three dimensional graphics, virtual reality, virtual modelling, visualizations and communication technologies, to reinforce nano-associated scientific and technological concepts. This suggested approach will indisputably fuel emotional engagement (through amusing training sessions) among nano students and future workforce, as it will lead towards a sustainable learning environment. Budding nano students would be able to take virtual tours (for example using Virtual Reality (VR) goggles) to expand their knowledge of the concept of nanotechnology; considering also the fact, that it is the most cost effective way and an electrifying technique for staying absorbed with the subject matter for an extensive period of time. Earlier on, Zhu and Varma (2006) reiterates that it is a challenge for engineering technology educators to develop new content and new teaching and learning tools for nanotechnology education, to prepare the new generation of engineering workforce for the nanoscale technology, but it is a challenge worth taking.

2.4.2 Nanotechnology Awareness

Fonash (2001) stresses that the fundamental constituent in engendering a nanotechnology workforce is general awareness among secondary school students; that which involves the appreciation of its role in society, its preparatory prerequisites and to stretch its subsistence to society. Fonash (2001) further elaborates that there was a time when the large practitioner of nanotechnology was the semiconductor microelectronics, considered to some, as a very cyclic, "boom and bust" industry. Nonetheless, it must be iterated that its horizons have widened today; in the sense that nanotechnology has proclaimed its unlimited status by spreading its wings across many economic sectors, enabling us to see enormous potential, sleeting from these sectors, which could improve a broad array of human activity and thus leading to a continuous and rapid development of nanotechnology.

Duell (1999) state that the champions advocating nanotechnology suggest that the utilization of limitless supply of atoms to manufacture valuable molecules will be able to meet world's needs. Crow and Sarewitz (2001) states that nanotechnology has the collective capacity of remaking the social, economic and technological landscapes through a constituting array of emerging set of science-based technologies. Nai (2013) states that the combination of nano-materials and nano-electronics has enabled advances in applications, including energy (e.g. photovoltaic and fuel cells, light emitting diodes, batteries), biotechnology and medicine. Prior to this, Mehta (2004) had endorsed that the prospective array of nanotechnology applications is staggering and the cost of undertaking basic nano research is high. The fact that nanotechnology has become multi-sectorial and does not represent a sector of its own, has compelled governments and international organizations across the world to begin seeking ways and methods to stimulate its development, while at the same time safeguarding the global environment, global health and global safety. Nevertheless, even if and after nanotechnology becomes acknowledged as a standalone sector, a great deal needs to be accomplished. Not only has nanotechnology gradually "reserved a special seat" in almost every economic sector to date, it has also left an impact on different stratus of society, which includes nano scientists, nano product developers, nano businesses, policy makers and civil society. Their role in spreading information and raising awareness on the implications, ethical, legal and social aspects of nanotechnology channel a good start towards tracking nano-technological progress and constructs a pathway towards boldly acknowledging the adverse side effects of nanotechnology. Rip (2006) state that recent developments indicate that that co-evolution of nanoscience/ technology and society is becoming reflexive, and that sociological enlightenment may play a role in this phenomenon.

Through a 1,500, self-reported questionnaire survey that was carried out in Taiwan, Mei-Fang et al (2013) clearly states that as an individual's positive attitude towards the technology increases, his or her perceived risks from applying nanotechnology also increases. Munshi, et al (2007) claims that in such an era, dialogues around nanotechnology struggle with tensions around the confines of the real and the hyper-real development and disaster, human and the post-human. In view of the fact that scientists and nano product developers already possess the technical knowledge and prowess in this field, they should lead the path towards nanotechnology awareness in education. Earlier, Colvin (2002) had argued that in the history of technology, nanotechnology has a unique opportunity; and points out that it could be the first platform technology bringing together a culture of social sensitivity and environmental awareness, during the early stages of the technology development lifecycle. Budding research students or secondary students (one of the society stratus mentioned by Fonash (2001) should translate their findings into simple dialogue processes, for effortless interpretations. On the other hand, nano businesses, which are commercializing nano based products, need to engage with the public, by informing them the implications of nanotechnologies and provide them with in-house knowledge regarding their products through collaboration with research universities and even schools who are keen on exposing their students in this subject. This in-house knowledge, resulting from within these businesses themselves, will serve as a revelation. The civil society remains to be the most important strata in society, because it is pertinent to learn of their apprehensions and critiques and thus not losing out on their nonprofessional insights. Colvin (2003) states that in the new century, emerging technologies face a more sceptical and demanding public. Through a survey collected from 870 students after reading the "Nanooze" magazine, Waldron, Batt and Lui (2011) concluded that the magazine was an effective medium for engaging middle school students and its dissemination led to the understanding of nanotechnology particularly in topics, such as health applications of nanotechnology, nanostructures and phenomenon.

The civil society will consist of members from academia, burgeoning students, general civilians and government policy makers. Until this day and this point of time, there has not been a stringent regulation for nanotechnologies. Existing regulations in other countries are still not adequate. Public should be informed with the latest updates through dissemination of brochures and workshops portraying the policymakers' qualitative and quantitative findings. These workshops held at university lecture theatres or school halls to egg on participation from schoolchildren and members of academia. This will positively stimulate a healthy debate on the pros and cons of nanotechnology among all stratus of society including optimistic educators who should look forward to getting their students excited about the expanding field of nanotechnology. Nanotechwire (2008) reported a new survey carried out by Lux Research, using top executives at 31 leading global corporations active in nanotechnology, concluded that awareness of nanotechnology is still growing and that 65 percent of global corporations say that senior management have high nanotechnology awareness, almost double of what companies said two (2) years ago.

2.4.3 Background Education: Unified Disciplinary Approach

Fonash (2001) argues that the nano workforce should have an expansive understanding of principles ranging from biology, physics, chemistry and engineering; all of which combined provides the basic concepts of nanofabrication and that of which leads to an understanding of nanotechnology. It is within this context that the author prescribes a need of a 'unified approach' to understanding and using science and engineering. Salerno et al (2008) stresses that any scientific discipline can be studied at the nanometre scale. Nanotechnology is truly interdisciplinary[14] (Uddin and Chowdhury, 2001); (Hersam, Luna, & Light, 2004); (Salerno et al, 2008); (Hall, 2005 *In* Palmberg, 2008); (Chih et al, 2012); (Allarakhia and Walsh, 2012); (Jain, Hallihosur and Rangan, 2011) and (Guan & Zhao, 2013). On the contrary to these authors, other authors such as Vogel and Campbell (2002);

[14] Interdisciplinary is defined as the faculty from different disciplines working together on the same project (Mallon & Burnton, 2005)

Schummer (2004); Bhat (2005); Avenel et al (2007); Ernst (2009); Holley (2009); Battard (2012) reflect on nanotechnology as a multidisciplinary[15] field of technology rather than an interdisciplinary one. It is a field that is at the crossroads of many disciplines (Battard, 2012). In favour of assimilating nanotechnology into the undergraduate curriculum, Uddin and Chowdhury (2001) had listed the integration of the following courses:

a. Nanotechnology I: Fundamentals of Nanoscience
b. Nanotechnology II: Synthesis Processing and Manufacturing of Nanocomponents and Nanosystems
c. Nanotechnology III: Design, Analysis and Simulation of Nanostructures and Nanodevices

These studies, indicated above clearly demonstrate the fact that nanotechnology has developed into both an interdisciplinary and multidisciplinary field. Vogel and Campbell (2002) points out that education in the past has revolutionized by first laying an underpinning groundwork and then gradually building pyramids of knowledge step by step and has resulted in a highly specialized workforce. This approach has augmented departmentalization in academia; whereby each field has imprinted its unique way of thinking while allowing it to evolve its own unique languages and acronyms. The author further draws attention to the fact that an education system focusing on solitary disciplines will not provide sufficient training to graduate students. This profoundly justifies the argument made by Fonash (2001) about the 'unified approach'. However, the only distinction is that the point made by Vogel and Campbell (2002) referred to graduate students and not secondary students. Ineke (2008) points out that majority of educators prefer training students first in their own discipline at the undergraduate level (physics,

[15] Multidisciplinary is defined as the faculty from different disciplines working independently on different aspects of the project (Mallon & Burnton, 2005). Battard (2012) stresses that the collaboration between scientists from different disciplines can be understood by their scientific heritage and the barriers that are related to it, and how individuals use this knowledge from another discipline in order to produce a new scientific outcome.

chemistry, biology) followed by a specialization in nanoscience and technology at the postgraduate level. Some prefer a broad interdisciplinary basic training in different nanosciences followed by a specialization in a particular application area. Pai, et al (2006) reaffirms by stating that broad impact can be achieved by curricular enhancement and reform at the undergraduate level. The University of Washington's Centre for Nanotechnology was the first to set up their very first PhD Program in Nanotechnology in 1997 known as an "optional" PhD program, which involved nine (9) departments; and was not a standalone PhD program but an integration of many other scientific disciplines. Its impact is still unknown. Ten years ago, Roco (2002) reported that the foundation of engineering education would shift from the microscopic to the molecular and supra-molecular levels in the next 10-15 years. The author indirectly accords with the outlooks of Fonash (2001). Vogel and Campbell (2002) stated that nanoscale science and engineering provide a common meeting place for other scientific disciplines. Due to this convergence, Sweeney, Vaidyanathan, and Seal (2006) points out that given the interdisciplinary nature of nanotechnology research, there is a need for students and researchers to be competent in more than one field.

Palmberg (2008) reinforces that companies may also require an extensive array of knowledge inputs from diverse disciplines for the commercialization of nanotechnology. According to a study conducted by Iyuke, Cross, Iyuke, and Potgieter, (2007) in three (3) faculties, within the University of Witwaterstrand (Wits) in South Africa, the university does not have any institutional policy in nanotechnology. However, the university supports nanotechnology initiatives, offers a conducive environment for interdiscplinary research and adopts a non bureaucratic approach, which increased the number of academics to patent their research. The study also revealed that Wits faced a major challenge, whereby there were inadequate schools involved in this field and inadequate industrial awareness. Ugo (2013) reports that MINATEC[16], a regional innovation cluster in Grenoble, France was created to foster development in the field of micro and nanotechnologies. Study results of Robinson et al (2007) indicate that clustering in nanotechnology has remarkable dynamics and the success and failure of the cluster to be stimulated, will in part be associated to the degree of success in agglomeration of technology platforms. Wonglimpiyarat (2005) recommended that universities should set up metrology[17] and measurement standards (from micro - nano meter) for nanotechnology commercialization and industrialization.

2.4.4 Training and Skills: Manufacturing Capability

In the area of nanotechnology, Roco (2001) believed that "training people is a key component for long term success". Fonash (2001) regards the most demanding nano educational task of all is the creation of a technical workforce for manufacturing, which requires "hands on experience" ("*capstone experience*") from top down to bottom up nanofabrication processing that is science grounded and skill-based, to make-fit into multiple industries. The author suggests collaboration between research universities and two – year colleges to achieve this concept. Uddin and Chowdhury (2001) affirm that

[16] Ugo (2013) reports that Grenoble INP – Grenoble and the Institute Polytechnique de Grenoble, one of MINATEC's founding institutions has set one of its main campuses, Campus Phelma (for Physics, Electronics, Materials"), at MINATECH and that students can gain admission into Phelma after two years of university level study to pursue advanced undergraduate education, Masters and PhD programmes. The report did not explicitly indicate which specializations were offered within these three fields, in all three levels of tertiary education. The report also did not mention what has been the total number of graduates from advanced undergraduate education, Masters and PhD graduating with degrees specializing in the field of nanotechnology from Phelma, out of the total number, enrolled from the time of its establishment, which was in 2006 (seven (7) years ago) to form a productive measure. There is no indication of a nanotechnology standalone programme set up in Grenoble INP. Ugo (2013) reports that it is not short of other productive measures, in terms of scientific publications, patents and research partnerships considering its short-term establishment of 7 years. These measures, however, is associated to a mixture of internal and external participation and not specifically that of MINATECH's alone. Therefore, these indicators does not fully measure the extent of how the establishment of MINATEC has contributed in terms of producing nanotechnology graduates in three fields over the past seven (7) years. Earlier on, Kautt et al (2007) had stated that it is interesting that there a very few centres that own a comprehensive micro-nano technology portfolio.

[17] Any activity within science and technology must be accompanied by reference measurements, to ensure that quantitative results are comparable and products interchangeable. In order to apply practical metrology the field of nanotechnology i.e., to make measurement in the nanometre range traceable to the SI units of length and angle, practical measurement standards must be constructed (Caneiro, 2001).

students will be able to work directly with established nanotechnology research centres to gain hands on experience. However, according to the National Nanotechnology Institute, there are only a handful universities in the US, Europe, Australia and Japan that offer selective graduate programs in nanoscience and nanotechnology that are in collaboration with research centres. In terms of vocational training, a study by EuroIndiaNet (2007) revealed that the development of individual courses or study paths specializing in nanotechnology for technicians is clearly just beginning; whereby Germany is the most active in this respect. Malanowski and Zweck (2007) reaffirms by stating that Germany has an excellent starting position for the economic realization of activities in nanotechnology. Light Feather (2005) claims, experts have estimated that the future demand will require 15-trained technicians for each scientist in a nanotechnology manufacturing business. However, Light Feather (2005) did not give any details of her source and motivation for this estimate. Chang (2002) characterizes traditional undergraduate engineering training as "inadequate to meet the challenges presented by the dynamic environment". Therefore, for a broader impact, there is a necessity to "reform the engineering curriculum at the undergraduate degree and aiming at all degree levels".

Schank (2007) reaffirms by stating that nanoscience education will need to make a sharp departure from traditional ways of teaching. Chang, Fan, Yang (2004) emphasizes on the fusion of class lectures and hands on experiments. Based on the principles of Just in Time (JIT) Manufacturing pioneered in the year 1992, and in view of the fact that nanotechnology has not yet penetrated into grade schools, Lakhtakia (2006) had proposed that pre university education could be "primed" by the supplementation of Just in Time Education (JITE) experiences for nanotechnology (fused together with the techno sciences and the humanities) to enhance, but not to replace the current education practices. A JITE experience is a project that involves two (2) or more scientific and mathematical disciplines, required by a single student or a team of students that regarded as the end of semester, end of year and end of pre-university education experiences. Zieminski and Warda (2000); and Hosseini and Esmaeeli (2010) have pointed out the importance of education in the commercialization process of nanotechnology. Training in the field of nanotechnology, making use of academic opportunities, studying the existing conditions and training, in line with achieving ideal conditions and holding educational workshops are of great significance and can be effective in accelerating the commercialization of nanotechnology. Romig et al (2007) underscores the verity that nanotechnology is a convergence[18] of many technologies functioning at an interface (crossing point), requiring that differing skills be taught throughout the entire educational process from grade school and high school science, engineering, social studies and history through PhD programs in engineering, science, management and the humanities. As the blend between industry and academia needs human resources training to develop new industries, Wonglimpiyarat (2005) suggests that the government through ministerial intervention should support joint funding initiatives between industry and academia. Chih et al (2012) predicts that nanotechnology may generate new manufacturing and service models that will necessitate forward thinking by enabling disruptive innovation into the edifice of appropriate skills and knowledge, which can maximize the opportunities offered by the nanotechnology commercialization activities.

[18] Wonglimpiyarat (2005) calls nanotechnology a cross-border technology.

2.4.5. High-Tech Facilities and Expertise

In the attempt to educate and train the nanotechnology workforce and to strengthen the manufacturing capability, Fonash (2001) believes that, students should have some exposure to the state of the art experimental facilities (scientific amenities), which remains a financial challenge to colleges and universities. By enabling this, Uddin and Chowdhury (2001) believes that students would be able to partake in nanotechnology research and development projects and laboratory experiments. Recognizing the points made by Fonash (2001), Uddin and Chowdhury (2001), what the government and other key actors need to do is to adopt the responsibility to ensure that the infrastructure (Corbett et al, 2000) is in place to educate and train young scientist and engineers to develop future nanotechnology applications, concepts and products. Romig et al (2007) questions how many firms and industries are providing fiscal incentives to help determine actions to educate the nanotechnology workforce, in order to help ensure nanotechnology education will be of high quality and that it will require much needed support status and support. No data is available to determine this number yet. Juanola-Feliu et al (2012) asserts that significant academic freedom and significant involvement in new firms is the key. Guan & Zhao (2013) emphasizes that due to limited resources and expertise; firms find it very challenging to explore new technologies on their own.

2.4.6 Academic Entrepreneurship: The Correlation between Human Capital Scientist and Commercialization of Nanotechnology

Apart from research and teaching, a “third wing” has surfaced from the university over the last two (2) decades, which is academic entrepreneurship that is specially designed to facilitate the commercialization of science (Etzkowitz et al, 2000 *In* Palmberg, 2008;). Adding support to this, Youtie, et al (2008), Battard (2012) and Chachamidou and

Logothetidis (2008) stress that the university's role has advanced from being a research and education traditionalist, to serving as an innovation-promoting knowledge hub. The dynamics and conduct of university research have correspondingly become more sensitive to industrial collaborative opportunities, commercial exploitation and increasingly transdisciplinary[19] (Loh et al, 2003). Wiek et al (2007) revealed that the missing agents, non-fulfilment of required functions, non-availability of required knowledge, and deviations between self and cross perception were critical constellations through an agent network analysis. The subject of university research commercialization has received immense interest and focus since 1980s (Farsi and Talebi, 2009). The population, who possesses the means to understand and implement the technology, is highly trained scientists, rather than technicians, engineers or business people (Feldman and Massard, 2002). The product development process requires substantial knowledge of the underlying science, as this knowledge is difficult to transfer, and the discovery and production functions are not separable.

Coccia & Wang (2014) stress that characterizations of radical technological innovations require basic scientific knowledge to passage through within the applied sciences, in order to engender solutions for socio economic problems. In addition, the appropriation of knowledge held by scientific researchers is necessary for successful commercialization (Zucker, Darby and Brewer, 1994) especially in the field of nanotechnology. Academic entrepreneurship[20] activities include: industry – university collaborations, university –

[19] Tress, Tress and Fry (2003) define "*transdisciplinary"* studies as projects that both integrate academic researchers from different unrelated disciplines and non-academic participants, such as land managers and the public, to research a common goal and create new knowledge and theory. Transdisciplinarity combines interdisciplinarity with a participatory approach.

[20] The "entrepreneurial university" is an attempt to transform aspects of higher education into commercial and market driven activities. This includes charging student fees, a reliance on external funding, an emphasis on training for work and the development of different types of universities around levels of teaching and research. Associated with this is an emphasis on the commercial benefits of intellectual property, the rise of an audit and regulatory culture and the introduction of private sector management principles to subvert public sector values (Deem, Hillyard and Reed, 2007).

based venture funds, university based incubator firms, start-ups founded by academicians, double appointments of faculty members in firms and academic departments and technology transfer. Knowledge management[21] process and the process of research commercialization are inter – related and have an interactive, supportive and complementary nature (Farsi and Talebi, 2009). The findings of Hoye and Pries (2009) who examined a dataset of 172 university faculty members reveal that commercialization is to a greater extent, extremely prone to be triumphant, if faculty members cleave to commercialization – friendly outlooks, soaring achievers in the research context and become highly involved in boundary spanning activities. This too applies to nanotechnology based research commercialization. Li (2000) confirms that Industry (I) – University (U) collaborations are beneficial in R&D cost reductions, dispersing risks, resource sharing and in the exchange of capabilities through complementary pairings. Palmberg (2008) identifies that the lack of business skills amongst university researchers are among the challenges that inhibit the active interaction between university researchers and private sector companies. Raesfeld, et al (2012) stresses that there has been little prior research conducted to study the performance of university – industry collaborations. However, according to Kenney (1986), Lerner (2004), Lowe and Ziedonis (2005), few studies indicate that commercial ventures involving academic scientists are often not successful. The findings of Nikulainen and Palmberg (2010) revealed that one could not unearth a significant effect of university - industry interaction on the involvement of researchers in nanotechnology. Nevertheless, their findings and the findings of Palmberg (2008) disclosed that in the field of nanotechnology, the most imperative and frequent

[21] Knowledge management is the task of developing, sharing and exploiting a university's tangible and intangible knowledge assets. Tangible assets include knowledge systems and the outputs of academic researches such as technologies, patents and market information. Intangible assets include the competencies and knowledge resources of human capital within the university (Farsi and Talebi, 2009).

modes[22] of interactive interdependency between industries (firms) - universities (researchers) take place in public R&D programs, conferences/seminars and bilateral R&D projects. Palmberg (2008) lays emphasis on the fact that the productivity slowdown of the 1970s and 1980s in the United States was partly considered a result of sluggish rates of commercialization of university research. Juanola-Feliu et al (2012) highlights that today, universities seek to cultivate "interactions and spillovers" in an attempt to bond research with "application and commercialization", thus, the processes of the formation, attainment, dissemination and consumption of knowledge are at the nucleus of the university's functions. Asmatulu, et al (2012) state that research and development on nanotechnology and nano-products, have been growing rapidly for more than a decade unlike educational progress, which has not been as fast as technological development.

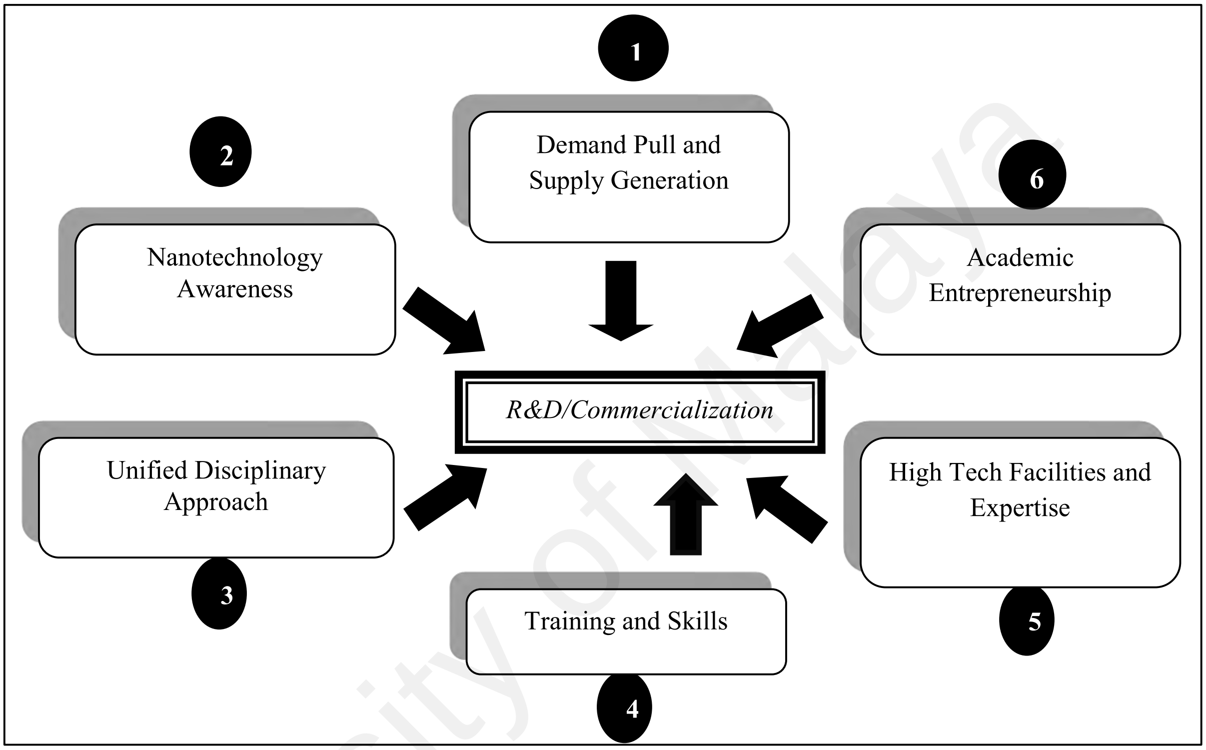
2.4.7 Précis: Nanotechnology Education

The preceding sub sections of literature on the demand-pull and supply generation, nanotechnology awareness, unified disciplinary approach, training and skills, high tech facilities and expertise and academic entrepreneurship have imparted adequate support that they are imperative key drivers towards the production of knowledgeable human capital necessary for the commercialization of nanotechnology as in Figure 2.3. During the examination of literature of these key drivers (1986 – 2013), many questions were deracinated and their answers have been dealt with in Chapter 5: Findings of this thesis. These questions will pave a way towards gaining intellectual and dynamic insights of what

[22] Juanola-Feliu et al (2012) and Palmberg (2008) state that "very little is yet known about favourable conditions for the transfer of nanotechnology to industry, as well as how the modes and challenges of technology transfer affect the development and commercialization of this emerging field".

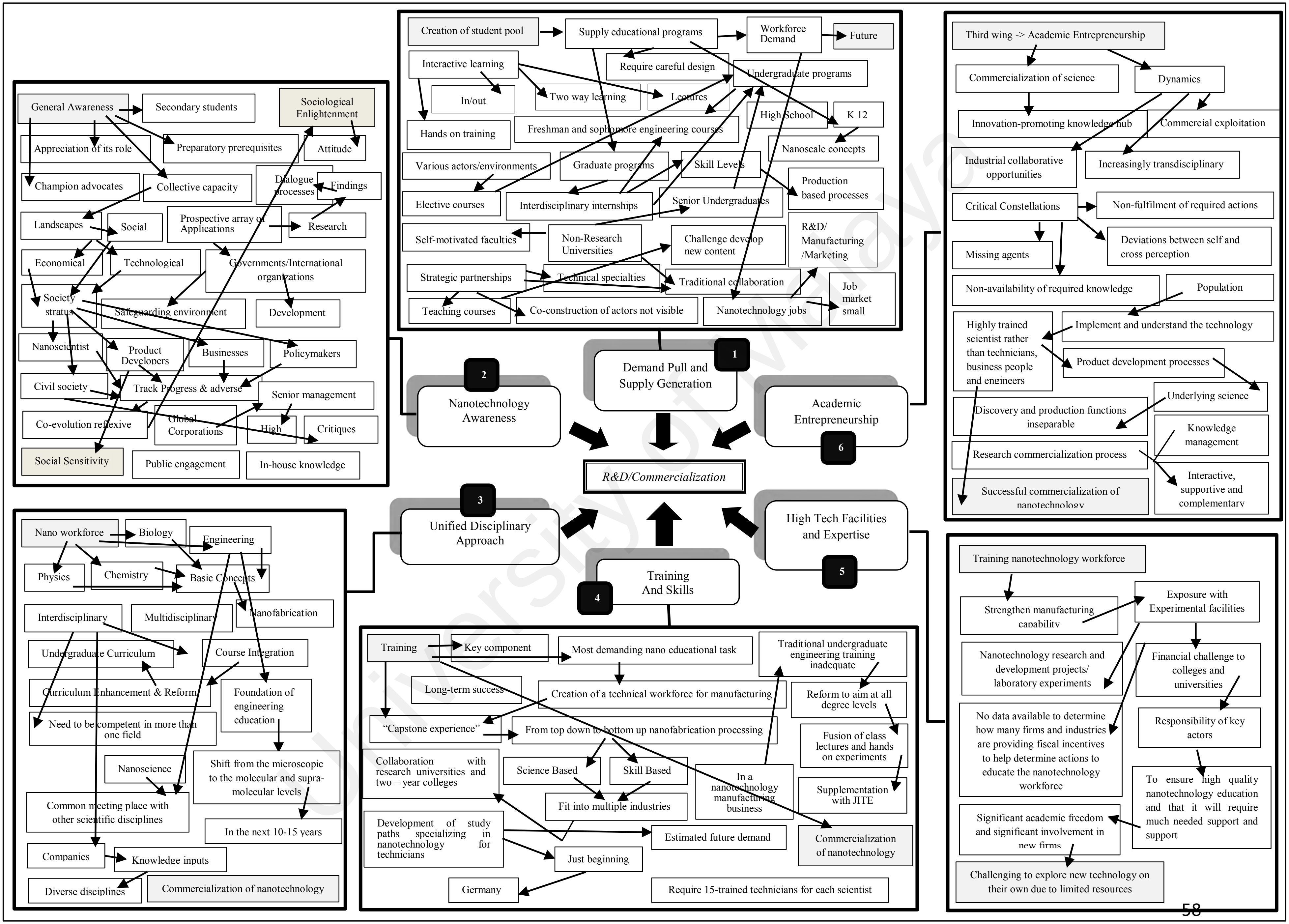
are the barriers towards nanotechnology commercialization from the stance of workforce development and education.

Figure 2.4 Nanotechnology Education that Impact the Technology Commercialization Process



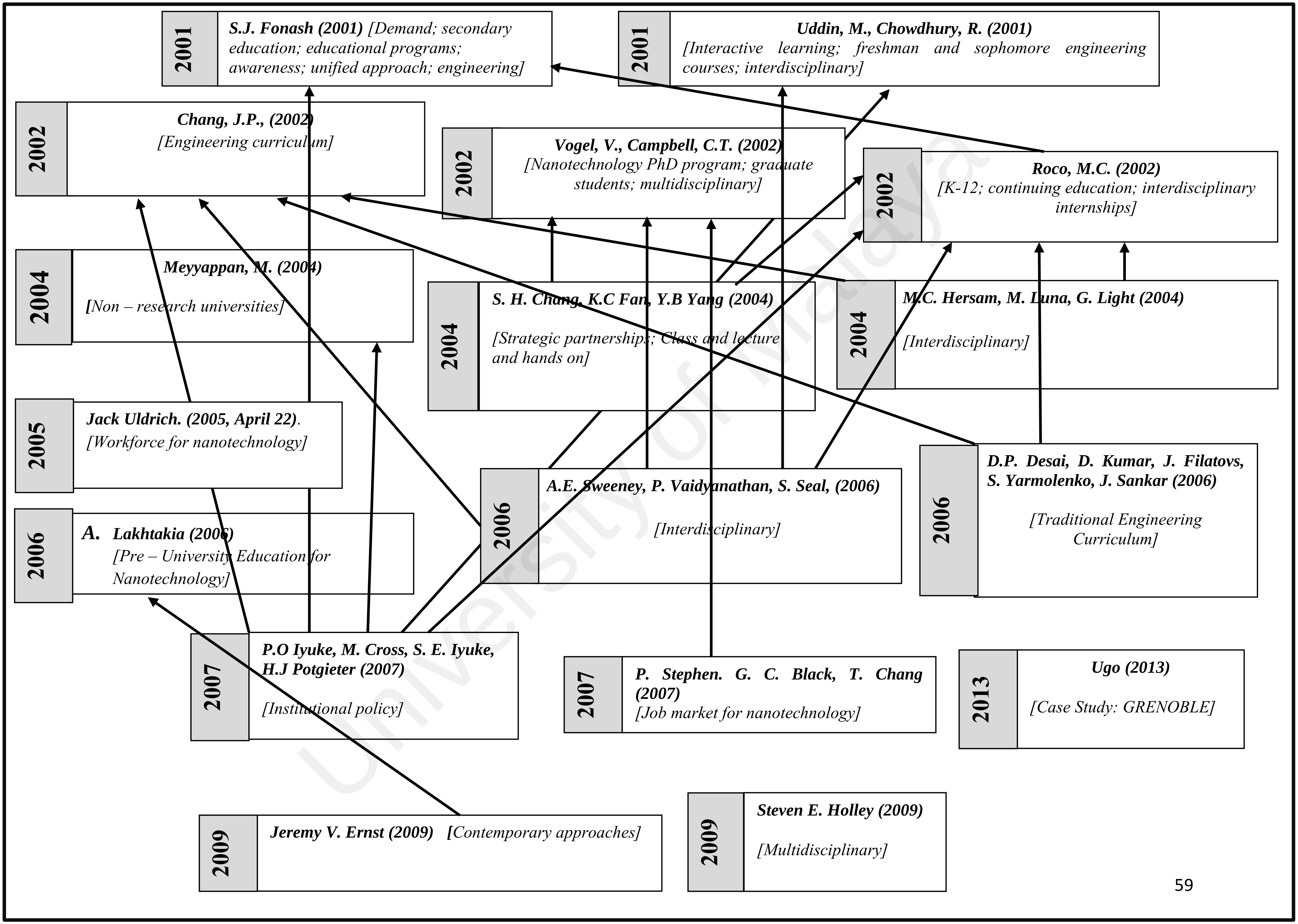
Source: (Author's Design) (Note: 1- 6 are key drivers towards the production of knowledgeable human capital required for the commercialization of nanotechnology)

Figure 2.5 The Major Aspects of Nanotechnology Education and Training



(Source: Author's Design) Note: These six (6) major aspects were identified through a series of literature review on a time series basis of core referred journal articles in the area of nanotechnology education and in the area of technology commercialization (1986 – 2014)

Figure 2.6 Time Series Review of Core Referred Journal Articles in the Area of Nanotechnology Education



Source: Author's Design

2.5 Nanotechnology Patenting and Publications

Some studies seek out to identify with the processes that determine the productivity of authors and inventors in new technology, as measured by counting of articles and patents. Moreover, bibliometric quantification has provided an effective way to show the emergence and development of a new technology (Islam & Miyazaki, 2007; Islam & Miyazaki, 2009, 2010; Leydesdorf & Zhou, 2007; Meyer, 2001; Braun, Schubert and Zsindely, 1997). Patents reflect the ability of transferring scientific results into technological applications (Hullman, 2007; Jain, 2011), thus they are a prerequisite for economic exploitation of research results and is central for any analysis that deals with economic potentials of emerging technologies (Leitao and Baptista 2009). Yet, the definition of what is a nanotechnology patent is a difficult task, given the newness of the field and the numerous scientific and technical areas involved (Fiedler and Welpe, 2010).

Previous studies on nano scientific publications such as Meyer's (2001) analysis based on the SCI database, included 5400 nanotech related papers focusing on the period of the 1990s, revealing S–T linkage between patents and publications; Hullmann and Meyer's (2003) study with SCI papers from 1981 to 1998, delineating nanotech from the so-called nanoscience (encompassing scientific disciplines affected by the nanotech revolution, but pursuing mostly basic research) and recently Leydesdorf and Zhou (2006) with an analysis of China's performance in nanotech, focused on journal-journal citation relations. With reference to nanotechnology publications in a whole, Braun, Shubert and Zsindely (1997) in their study established the fact that there is an exponential growth pattern in nano-science and technology starting in the early 1990s. The authors evidenced this finding, as a scientific indicator to prove the emergence of nanotechnology. According to a study conducted by Meyer & Persson (1998), which applied the same methodology as Braun, Shubert and Zsindely (1997), findings revealed that the share of boundary spanning (meaning the “bridge” between an organization [university/college] and their exchange partners, competitiors and regulators), interdisciplinary and interfield publications are exceptionally high and still growing. Nevertheless, in an attempt to investigate the comparison between patents and publications, Meyer & Persson (1998) substantiated through the use of aggregate data of various countries spanning from the year 1988 to 1997 (a 10 year period), stating that one cannot ascertain any causal relationship between papers and patents and therefore, implying that countries who are big in papers does not mean they are big in patents too.

Again coming back to and in light of the idea established by Braun, Shubert and Zsindely (1997) in provisos of the exponential relationship between nanoscience and technology, results from the study conducted by Meyer (2001) supports the fact that the two are still separate activities. Hullman and Meyer (2003) concur with this statement, stating that there are few connections between nanoscience and nanotechnology. The central finding of Meyer (2001) confirms that there are weak linkages (the total number of linkages are small) established by 181 nano patents that cite 275 nano science papers out of more than 5000. Consecutively, Hullman and Meyer (2003) indicate that universities authored more than half of the cited papers and their patent data reveal that the core activities were focused on electronics, instrumentations and chemical/pharmaceuticals. According to the analysis revealed by Hullman and Meyer (2003), countries that are most active in publications and patents were USA[23], Japan, Germany (top 3) and closely followed by France, Russia,

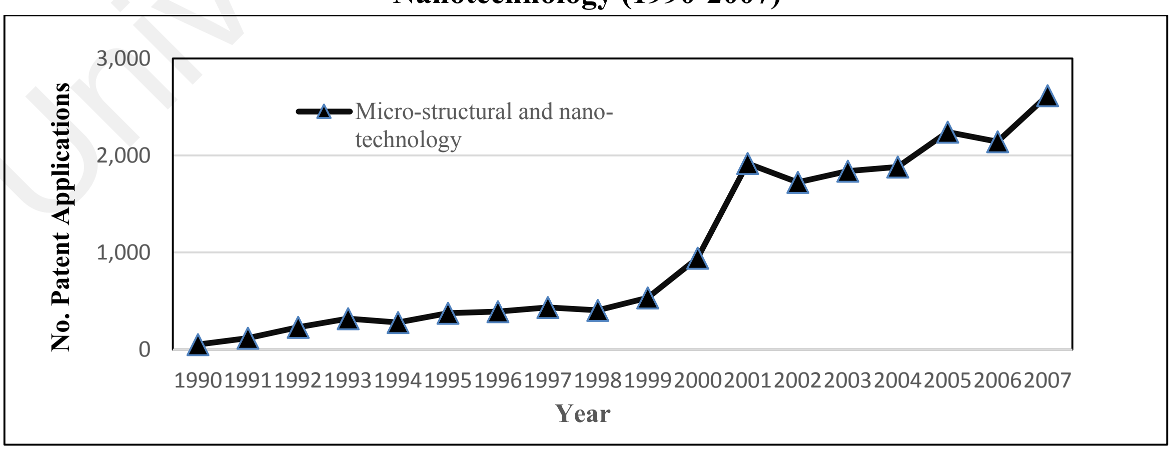
[23] When productivity per researcher and investment is considered, then USA is not the leader in nanotechnology publication; whereby it has trailed its European counterparts in all studies, behind Japan and Korea (Motoyama and Eisler, 2011).

China[24], South Korea and Poland. This however, contradicts with the recently published report by Marks and Clerk (Kinsler, 2006), that sees Europe lagging behind Asia and the USA in the annual rate of filling nanotechnology patents (Pandza and Robin, 2007). Large increases in the late 1990s and early 2000s distinctly mark the growth escalation of the number of nanotechnology patents. The development of the number of patents originating from the United States is very similar to the overall development of all nanotechnology patents, whereby for scientific publications, not all share the same quality and being active, does not necessarily create an impact (Hullmann, 2007). By co-authorship analysis, Schummer (2004) investigated over 600 papers published in "nano-journals" in 2002 and 2003 and concluded that entire field of nanoscale research shows only an average degree of interdisciplinarity, comparable to classical disciplinary research, but a high degree of multidisciplinarity. Nevertheless, Leydesdorf and Zhou (2007) iterates that it is not possible to delineate nano-journals clearly from other journals relevant in the direct environment, such as disciplinary journals in Chemistry and Physics, and general science journals like Science and Nature. Meyer (2006) suggests that certain fields of nanotechnology are not as drawn to patenting as others and may be viewed as a reminder that nanotechnology is still a heterogeneous field of S&T. Motoyama and Eisler (2011) avers that the heterogeneity of citations and journal publications, further complicates the capability of researchers to measure science output in the case of nanotechnology, which clinches to several academic disciplines. Mangematin and Walsh (2012) underscores that the massive public financial ventures and the establishment of technological, industrial infrastructures have paved way to over 2,000,000 nanotechnology papers and more than 1,000,000 patent applications until today. Beaudry and Allaoui (2012) confirm that while more public research funds

[24] In terms of scientific output (published journal articles and patents), China is a candidate for upper – echelon status in the global nanotechnology endeavor (Hullmann, 2006). Upper – echelon in this context refers to the 'A-List".

undoubtedly lead towards increased scientific articles, the relationship between private funds and scientific articles are inexistent (receiving greater amounts of research funds from contracts does not have a reinforcing impact on scientific production in nanotechnology). According to WIPO Statistics Database (June 2010), the exact total number of patent applications is 1, 907, 915, but did not clearly specify the exact field of technology. The reason for emphasizing this statement is because, nanotechnology has yet to be acknowledged as a standalone sector by the International Classification Systems worldwide and therefore, if there are any statistics available on patent applications, the measurement indicated does not solitarily belong to the field of nanotechnology alone. Figure 2.7 shows the total number of patent applications specifically for the field of micro structural and nanotechnology from 1990 - 2007. Nevertheless, Meister and Meister (2005) emphasizes that the general definition of micro structural technology is very ambiguous and therefore, making it difficult to clearly distinguish its characteristics to that of nanotechnology. However, presently, these are the only available statistics, whereby, nanotechnology closely coupled to the field of micro structural technology.

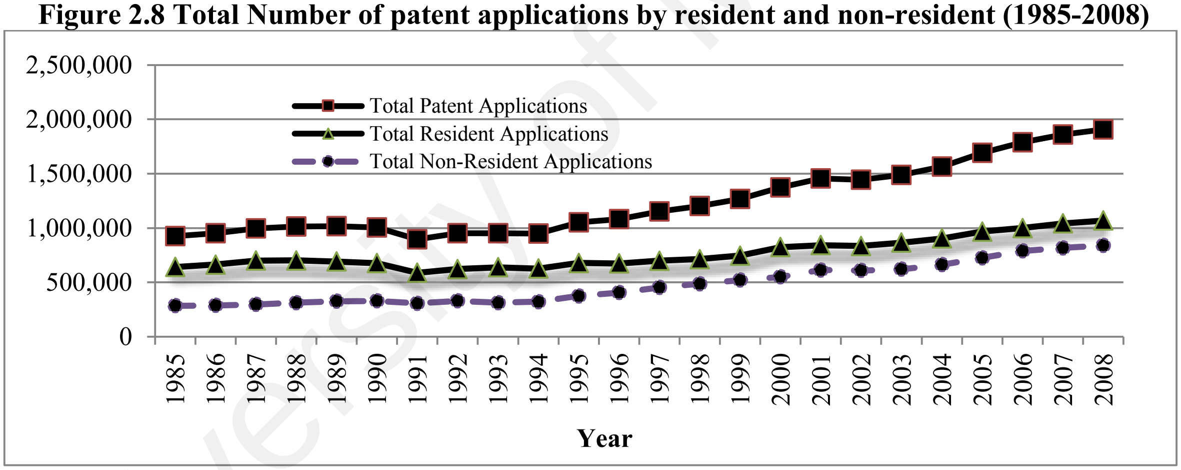
Figure 2.7 Total Number of Patent Applications for the Field of Micro-Structural and Nanotechnology (1990-2007)



Source: WIPO Statistics Database, September 2010

According to Figure 2.7, total number of patent applications for the field of micro – structural and nanotechnology has steadily increased from 1990 to 2001; however, in the year 2002, there was a sudden plunge in patent applications. Nevertheless, the number continued to rise again from 2002 until 2005. There was a slight drop yet again in 2006 but not drastically. Fiedler and Welpe (2010) states that as of 2010, articles on topics related to nanotechnology account for approximately 2.5% of scientific articles and approximately 0.7% of patents, indicate a sign of commercial potential for nanotechnology. Figure 2.8 shows the total number of patent applications by resident and non-resident (1985 – 2008) and Figure 2.9 shows the total patent applications by field of technology (1990 – 2007).

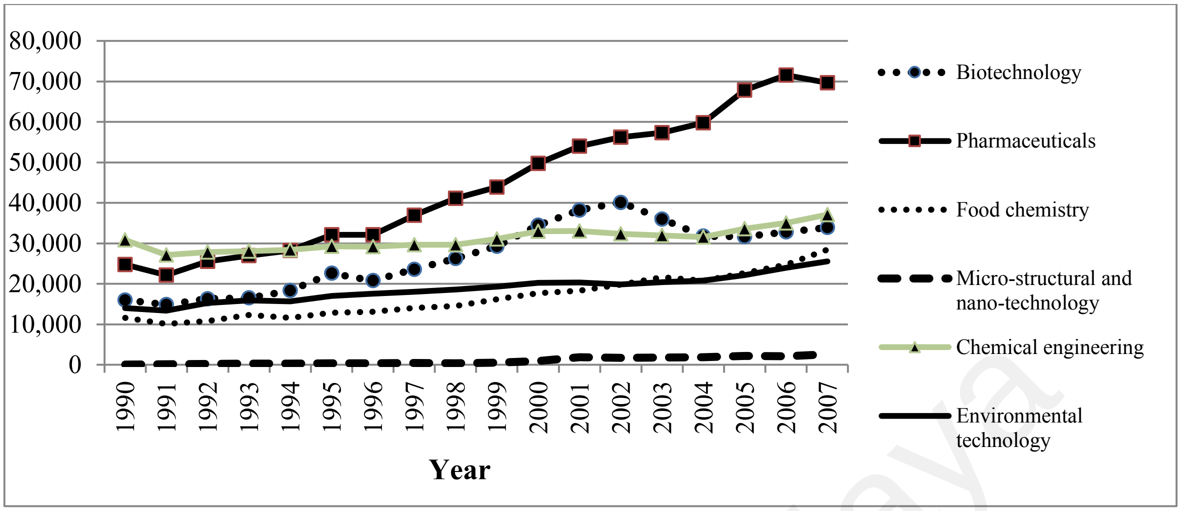
Figure 2.8 Total Number of patent applications by resident and non-resident (1985-2008)



Source: WIPO Statistics Database, June 2010

(Note: Data prior to 1995 may be downward biased due to incomplete reporting of PCT national phase entries. Patent applications filed with and granted by the EPO are considered non-resident applications. The world total is a WIPO estimate covering around 110 patent offices)

Figure 2.9 Patent applications by field of technology (1990 – 2007)



Source: WIPO Statistics Database, September 2010

(Note: The International Patent Classification (IPC) symbols assigned to the patent document are linked to the fields of technology by a concordance. Because a patent application may be assigned multiple IPC symbols, the sum of patent filings by fields of technology is higher than the total number of patent filings)

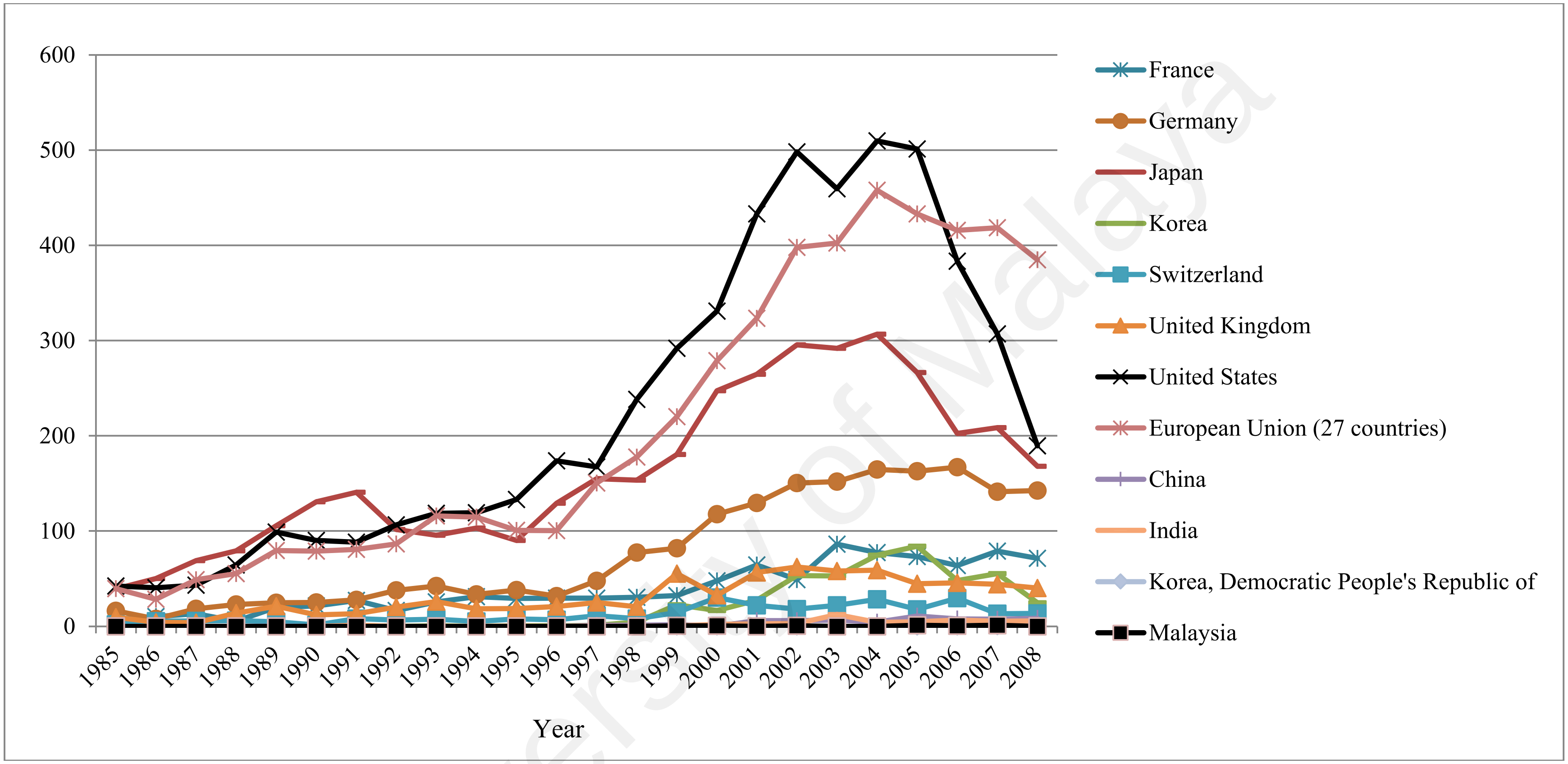
2.5.1 The Correlation between Patents, Publications and Commercialization

In quantitative terms, Motoyama and Eisler (2011) states, that there is high correlation of 0.84 – 0.99 between the number of nanotechnology publications and the number of total publications in science and engineering. Fresh new products are the ultimate consequential effect of R&D. Therefore, Tolfree (2006) emphasizes that it is research and development, which spawns the knowledge and intellectual property[25] (IP), but the real wealth comes from the commercialization of that IP. The design team will entail unlimited entrée (access) into this abundant yet affluent knowledge and be aware of patents and other developments that could influence the outcome. The author also emphasizes that patent searches (the

[25] After an examination as to whether nanotechnology falls within the auspices of Article 27 of the World Trade Organization Intellectual Property Right (TRIPS) Agreement, Diana (2007) clarifies that the emerging nanotechnology does fall under the scope of patentable subject matter within international IPRs. But, while the TRIPS agreement does not pose any challenge to the patenting of current nanotechnology applications, Diana (2007) states that the blurring of the invention/discovery interface and the probable convergence of nanotechnology and biotechnology in the medium term, which may produce uncertainty over the types of nano-products patented, may challenge the IPR regime. Minori and Toschi (2014) highlights that in order to fully comprehend the evolutionary and competitive dynamics of an industry, the question of the appropriateness of patent scope in the nascent stage of a new technology, and how this can evolve over time as the technology develops, represents pertinent conditional significance, in terms of underlying characteristics, timing, sectors of interest and type of applicant.

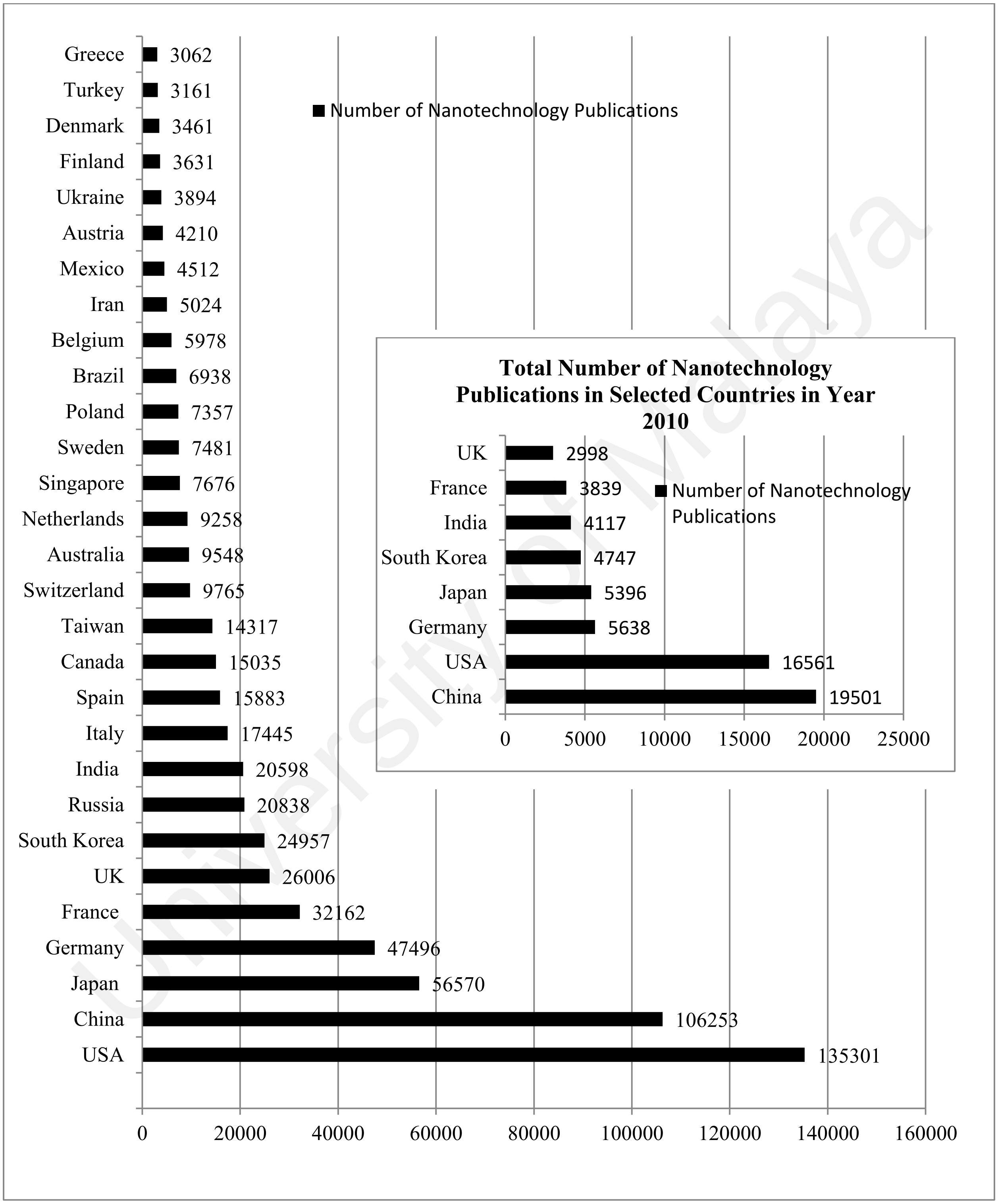
knowledge and thorough understanding of the patent process) and acquisitions (ownership of the IP) are the antecedent of the prerequisite along the path of commercialization. With regards to firms particularly involved in innovations off-shooting from emerging technologies, Valk, Moors & Meeus (2009) quotes Lemarie, el al (2000) by stating that the applicability of patent data in assessing the technological dynamics is unreliable and questionable to a certain extent, considering that firms venturing in emerging technologies are generally start-ups and do not even have patents yet, due to its high cost and even if they do, firms are unable to protect these patents, once infraction occurs. Figure 2.10 show the total number of patent applications in the field of nanotechnology in Selected Countries (1985 – 2008) and Figure 2.11 show total number of nanotechnology publications in selected countries (1975-2010).

Figure 2.10 Total Number of Patent Applications in the field of Nanotechnology by Selected Countries (1985 – 2008)



Source: Data extracted on 30 Mar 2012 08:47 UTC (GMT) from OECD.StatExtracts (http://stats.oecd.org/Index.aspx?DatasetCode=PATS_IPC#)
(Note (a): The above extracted data is based on the compilation of the patent applications made to EPO)

Figure 2.11 Total Number of Nanotechnology Publications in Selected Countries (1975-2010)



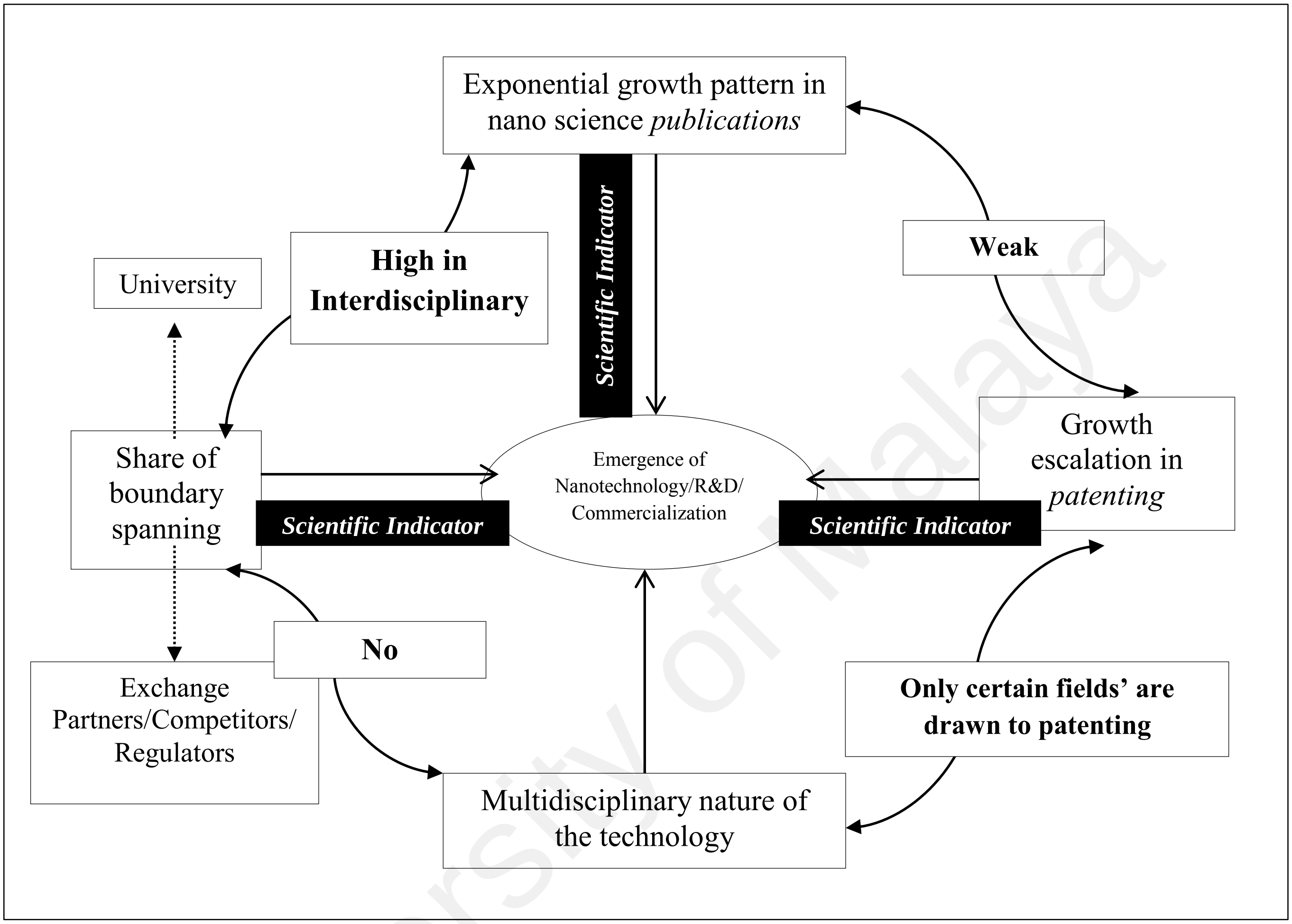
Source: Iran NanoTechnology Council Initiative (2012) [http://en.nano.ir/index.php/main/page/17] based on statistics extracted from ISI Web of Knowledge and Science Citation Index.

Nevertheless, Meyer (2006) states that not everything patented will be commercialized. When it comes to scientific papers, they are also considered as scientific indicators, capable of gauging the rate of progress in the field of nanotechnology. According to Chen, et al (2008), the papers that reported the invention of the Scanning Tunnelling Microscope (STM) in the year 1981 and the Atomic Force Microscope in 1986 is proof of scientific results in paper (publications) being translated into commercial success. Today the STM and the AFM are indispensable laboratory instruments required in the research and development of nanotechnology. Further, these authors also bring to light the reality that these papers have been cited numerous times by researchers, that which only adds further testament of the impact that these microscopic instruments have on the field of nanotechnology. The next section will briefly condense the factors that were recognized and carefully deracinated thru a thorough analysis and review of literature on nano patents and publications.

2.4.2 Précis: Nanotechnology Patents and Publications

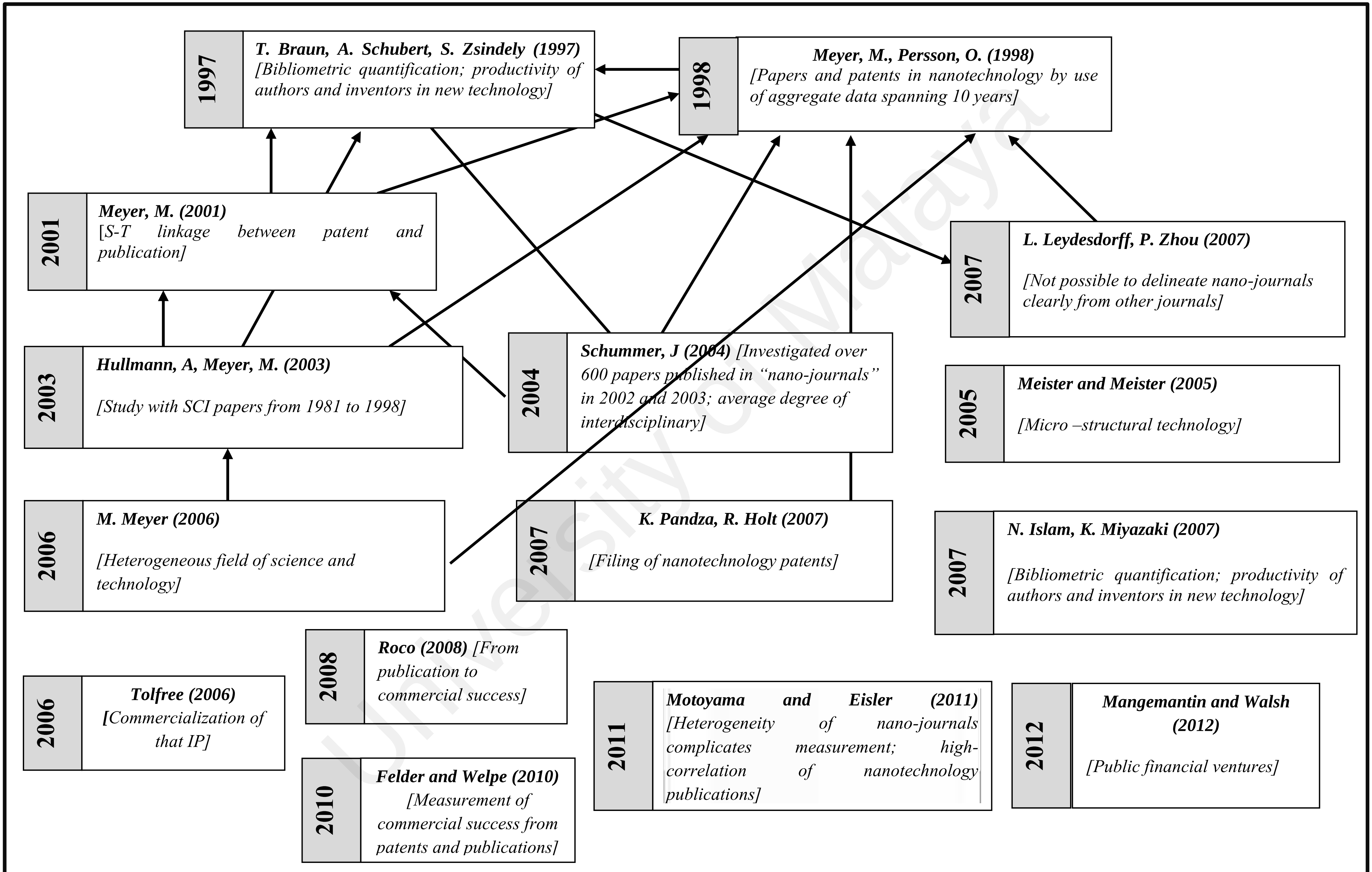
After a rigorous literature review of core referred journal articles in the area of nanotechnology patent and publications (1997 - 2010) as illustrated in Figure 2.13, it is evident there are several factors that influence the emergence of nanotechnology, R&D and commercialization. Figure 2.12 illustrates the influencing factors in terms of patents and publications. The factors identified here in this section are the exponential growth pattern in nano science publications, share of boundary spanning relationships, growth escalation in patenting and the multidisciplinary nature of nanotechnology. While these factors are contributing factors towards the emergence of nanotechnology, R&D and commercialization, in nowhere does it explicitly state that increased quantity of patents and publications equals to increased production of scientific outputs.

Figure 2.12 Factors Influencing the Emergence of Nanotechnology, R&D and Commercialization in Terms of Patents and Publications



Source: Author's Design
(Note: Factors Influencing the Emergence of Nanotechnology, R&D and Commercialization through a series of literature review on a time series basis of core referred journal articles in the area of nanotechnology patents and publications (1986 – 2014))

Figure 2.13 Time Series Review of Core Referred Journals Articles in the Area of Nanotechnology Patent and Publications (1997 - 2014)



Source: Author's Design

2.6 Nanotechnology – Based Innovation

2.6.1 Product and Process Innovations

Technological innovation[26] involves "invention[27] plus commercialization[28]", or the use of new knowledge to present a new product or service that consumer wants (Afuah, 2003; Schumpeter, 1934). Nanotechnology – based innovation is the subset of technological innovations that involves the broader application of knowledge and inventions developed at the nanoscale towards a commercial end. The potential contributions coming from broader application areas of these nanotechnology innovations is mammoth and will determine the rate of development and commercialization of nanotechnology – based innovation. Nanotechnology – based innovation varies from traditional biotechnology[29] - based innovations where phenomena occurring at the nanoscale are inferred rather than observed (Shea, 2005). Figure 2.14 represents an explanatory formula to describe nanotechnology-based innovation. Shea (2005) states that nanotechnology is a general-purpose technology. In addition to this, Shea et al (2011) claims that by virtue of its pervasiveness, investments in their development result in spill overs to other sectors of the economy, making it more difficult to control intellectual property rights.

Figure 2.14 Formula for Nanotechnology – Based Innovation

$$\boxed{\text{Nanotechnology- based innovation} = \text{Invention} + \text{Commercialization}}$$

Source: Adapted from Schumpeter (1934), Afuah (2003) and Shea (2005)

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[26] Technological innovations comprise new products and processes and significant technological changes of products and processes. An innovation is known to have been implemented, if it has been introduced on the market (product innovation). In most instances, this definition resulted from statistical standards developed by international organizations such as the International Monetary Fund (IMF), Organization for Economic Cooperation and Development (OECD), Eurostat and International Labor Organization (ILO).

[27] Nanotechnology invention refers to nanotechnology developments in materials and structures (e.g. nanotubes, nanoshells, nanowires, nanoparticles) and their fabrication and assembly processes.

[28] Nanotechnology commercialization refers to the application of nanotechnology developments in products in various sectors including materials, electronics, healthcare, environment, energy, robotics, security, metrology and many more.

[29] Rotharmel and Thursby (2007) argue that the variance between nano and biotechnology exist because the enabling technology of nanotechnology was commercially available much faster than biotechnology, which took over two decades. Business Dictionary.com defines the term "enabling technology" as equipment and/or methodology that, alone or in combination with associated technologies that provides the means to generate giant leaps in performance and capabilities of the user. For example, the coming together of telecommunication technologies, internet, and groupware has levelled the field so that even smaller firms are able to compete in areas where they otherwise could not.

Nanotechnology is seen as a breakthrough innovation and it is uncertain what sort of sectors will be impacted (or created) by nanotechnology innovations and how the regulatory, economic and societal landscapes will co-evolve (Robinson, 2009). Nanotechnology expectations are not exclusively about industrial innovation but the creation of a generic industry that will infiltrate and transform other industries. Exhibiting the epitome of creative destruction[30], nanotechnology advocates claim that nanotechnology will redefine existing industries and array them in new combinations, changes being already underway, as sub-micronic technologies entangling communication and information industries (Barezo et al., 2007). Colombelli, Kraft and Quatraro (2014) states that actions to encourage the emergence of new technology based industries, such as nanotechnology should be based on the accurate analysis of both the comparative advantages developed over time and its relative position in the technological landscape. However, Hung and Chu (2006) concludes that speeding up the transition process from emerging technologies to new industries is central to successful economic growth.

Few studies by Nicolau (2004); Bonaccorsi and Thoma, (2007); Martin, M. (2007); Nazrul Islam & Miyazaki, (2007) argues that nanotechnology is both a radical technology, creating technological discontinuity[31], and an incremental technology[32], building more on existing knowledge. Meyer (2007) explicitly points out, that there is no denial of the possibility of radically new knowledge and innovations, but rather to stress, that the breadth of innovative

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[30] Creative destruction is defined as the process of economic renewal through which companies that offer outdated products and services, and creates little value, is replaced by companies better adapted to current and future requirements, and creates more value. First observed and described by the economist Joseph Schumpeter (Source: http://www.getinstitute.com).

[31] Christensen, Clayton (1997), Gary Hamel and Prahalad (1994), and James Utterback (1996) as quoted by Soren Kaplan in his book entitled "Strategy and Leadership" describe discontinuous innovation as involving "disruptive technologies," "discontinuities," or "radical innovations" that permit entire industries and markets to emerge, transform, or disappear.

[32] "Incremental technology innovation" can be defined as a managed change in the process technology that an organization uses to deliver its products or services that modifies or builds upon the existent process or technology (Joseph M. Katz, 2008). Von Hippel (1988) states that innovation in the perspective of innovative organizations is a process of incremental improvements.

activities in nanoscience and nanotechnology (N&N) tends to be of incremental nature. It is very likely to occur along established technological trajectories (the ways industries develop and introduce new technologies) (Pandza, et al, 2011). Avenel, et al (2007) distinguished two (2) trajectories that firms can follow: One is to hybridize the existing knowledge, the second to exploit breakthrough knowledge. However, Raesfeld, et al (2012) concludes that the impact of these firm trajectories have not been examined hitherto.

Nikulainen & Palmberg (2010) highlights that in future, when the technological trajectories associated to nanotechnology become more clear and the roles of discontinuous and incremental advances is more evident, further can be said of the uniqueness of nanotechnology with regard to the diffusion of scientific knowledge. No & Park (2010) conclude that collaboration", "technological fusion", "technological convergence" and "cross disciplinarity" have become the new descriptors of knowledge, resulting from the change in techno-paradigms and the present impulsion for high technology. As opposed to the terms used by No & Park (2010) with regards to "technological fusion", "technological convergence", Maine, Fraser and Utterback (2014) define "technology confluence" as a new combination of previously distinct technologies, and evolves when researchers begin to work at the intersection of two or more technology streams, and when products based on this intersection of technology begin to emerge". In line with Meyer's argument, Pandza & Robin (2007) endorses the fact, that even if novel products or services do integrate some nano-enabled solutions, these are more likely to be incremental improvements of existent ones. Two (2) years before, Shea (2005) had earlier asserted that when faced with an incremental innovation, competition shifts to product features and process efficiencies. Nevertheless, amidst all these studies on nanotechnology innovation (radical, incremental, existing knowledge or breakthrough knowledge) conducted from 1934, 2003 right up to 2014, there has not been any indication of the time necessitated in transforming a nanotechnology prototype into a fully-fledged product, and whether or not this time factor acts as an obstruction towards research and commercialization of nanotechnology. This section will further discuss the subject of product and process based innovations. Linton and Walsh (2008) points out that for process-based products, product and process innovation[33] are tightly coupled and in their paper concludes that process based innovation requires diverse management and commercialization strategies than product-based innovation.

Nanotechnology can be characterized as a process based innovation (Linton and Walsh, 2008). Process innovation in nanotechnology is frequently linked with high-ceilinged levels of uncertainty concerning the eventual manufacturing costs, and steepness of the learning curve (Linton and Walsh, 2004). As a result, the degree of consumer acceptance (whether or not the product attributes satisfy consumers' demands) must be taken into account when commercializing nanotechnology processes (Chih et al, 2012). From the commercial perspective, Mangematin and Walsh (2012) proclaims that consumer awareness is by means of the products' greatly increased functionality and internal design; given that from the physical perspective, individual nanotechnologies are invisible to the human eye. Chih et al (2012) avers that there are no comparative studies investigating the commercial

[33] Schumpeter (1934) classifies innovations in two major categories: Product and process innovations. Product innovations comprise '…the creation of a new good which more adequately satisfies existing or previously satisfied needs". Product innovations also include the creation of completely new products, which provides a monopoly position to the innovator. A process innovation replaces "…one production or consumption good by another, which serves the same or approximately the same purpose, but is cheaper". According to Schumpeter (1934), process innovations also include introducing new materials or supplies that have the potential of producing a unit of a product cheaper.
Utterback and Abernathy (1975) define product innovation as "a new technology or combination of technologies introduced commercially to meet a user or a market need." For them, a production process is "the system of process equipment, work force, task specifications, material inputs, work and information flows, etc. that are employed to produce a product or service", thus a process innovation is the improvement of process elements, a production unit's internal organization structure, supplier interaction, etc. to improve efficiency and output productivity of a production process.

performance[34] of nano-products subsequent to their introduction in the market and the customers' response. Nanotechnology – based process innovations will dominate in mature industries, whereas new product innovations incorporating nanotechnology, will reform in their early development stage (Gulati et al, 2003), while nanotechnology product innovations are increasing (Mangematin and Walsh, 2012).

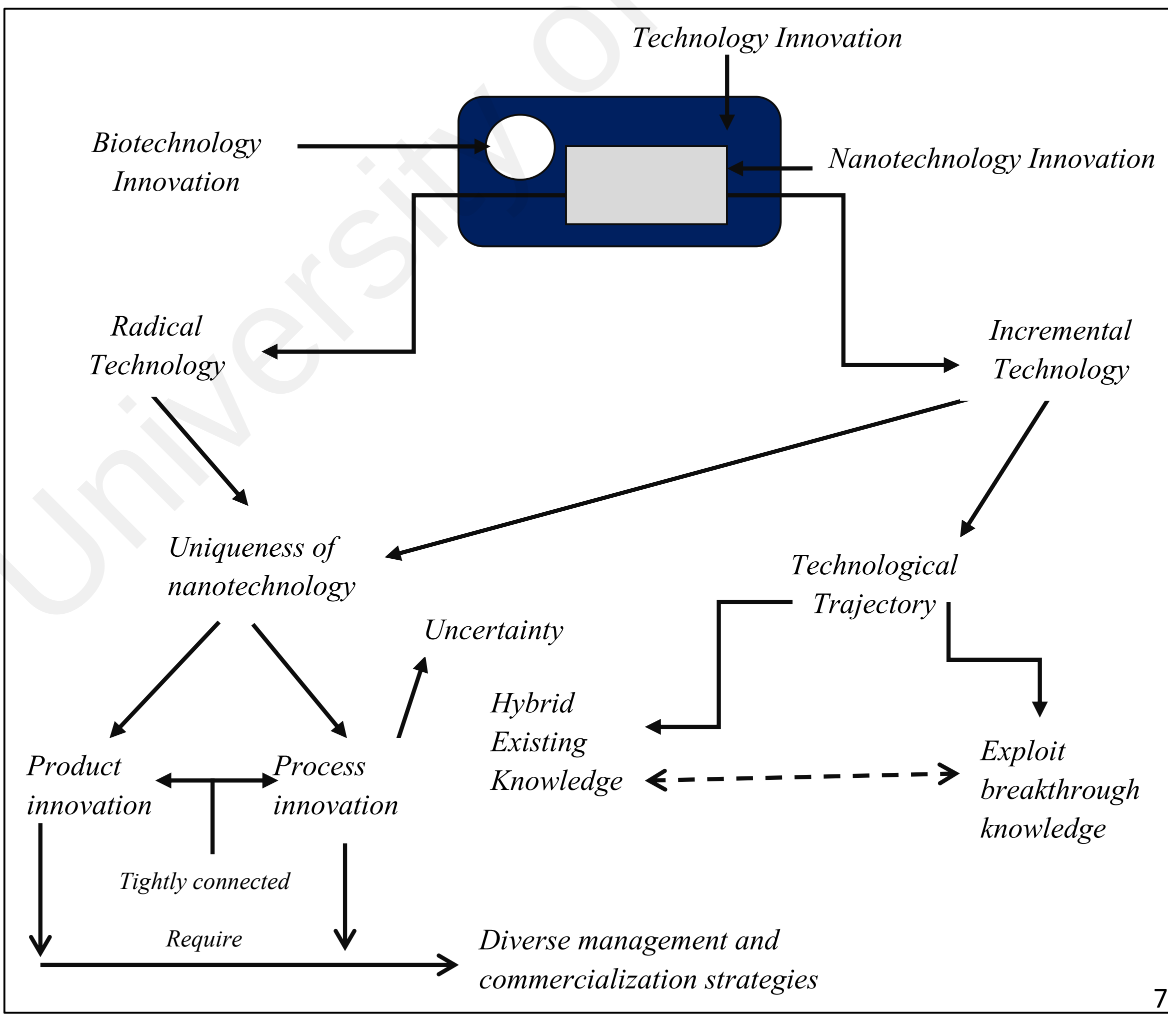
Further Maine et al (2012) explains that new ventures are a vital vehicle for commercializing radical technology and therefore, as new ventures try to commercialize nanotechnology, they develop value creation strategies to better link fundamental scientific advances with the creation of value for users and investors. Earlier on, Mazzola (2003) had asserted that given nanotechnology's nascent stage, there are understandably few investors taking risk in early stage innovation. Koehler & Claudia (2014) clearly points out that adverse risks resulting from emerging technologies can place firms at jeopardy for developing business strategies around its offshoot innovations and that the firm is necessitated to employ risk mitigation strategies, prior to market proliferation of these new, novel and unpredictable technologies. Merkerk & Lente (2005) emphasize that when it comes to emerging technologies, the tenet is that the stakes and anticipated outlooks are high and vary in different sectors of the economy at the same time fluid, erratic and there is no distinct knowledge of what the technology will bring in the future.

In the case of science-based technologies such as nanotechnology, Palmberg (2008) proclaims that small firms are deficient in research instrumentation, work force and other resources. Large firms are likely to be disinclined to invest particularly (Palmberg, 2008)

[34] If the characteristics and functions of nano-products are not properly analyzed, how well these products are accepted by consumers will remain unknown and the consistent improvement of nano products will be difficult. (Chih et al, 2012)

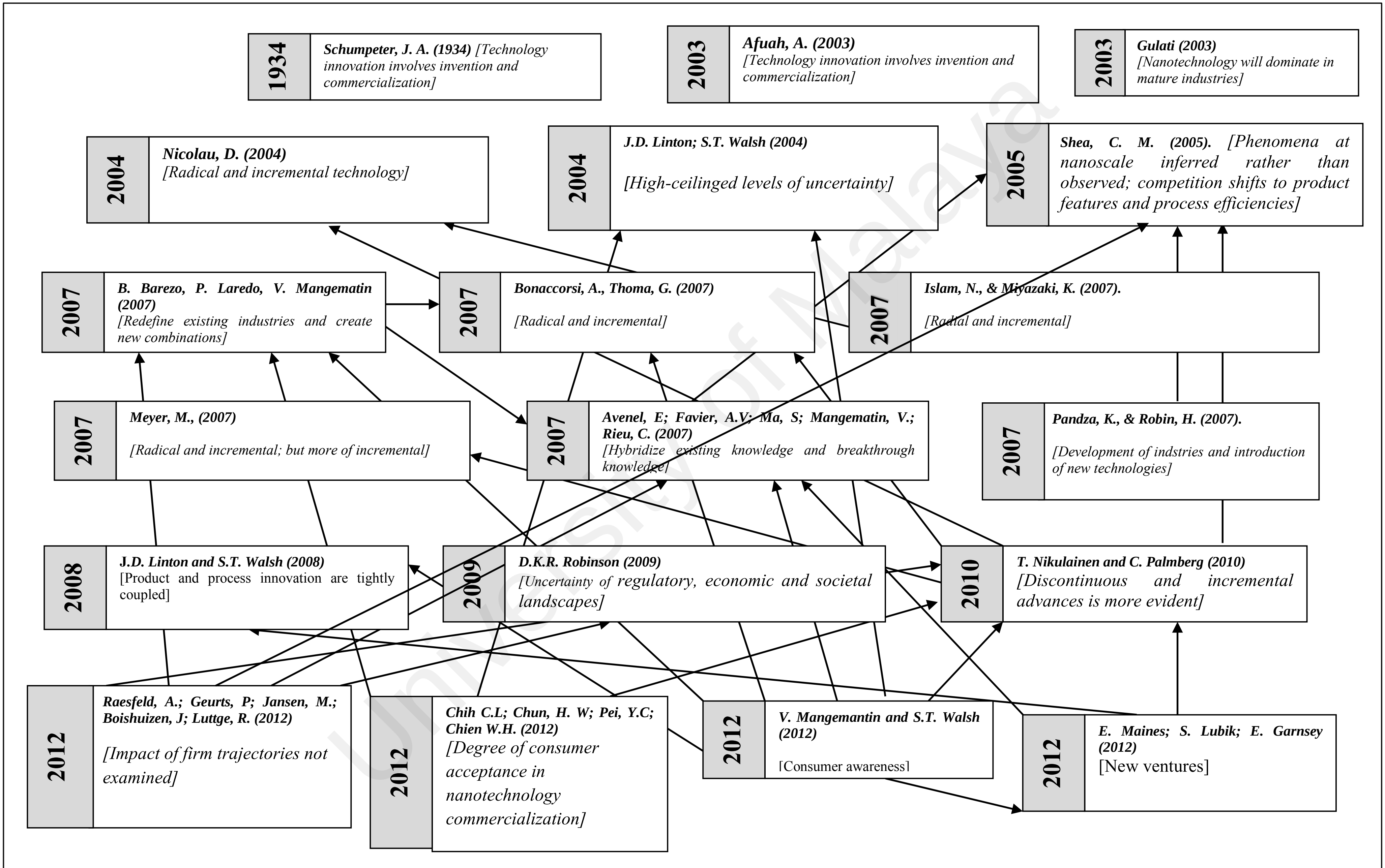
when technologies are in a position of uncertainty (Fiedle and Welpe, 2010) and premature phase of development (Chih et al, 2012). However, others may argue differently. Fiedler and Welpe (2010) believe that large firms usually have the expertise, own complimentary assets and own resources necessary for commercialization; thus, there might not be any need for them to cooperate. Figure 2.15 illustrate the elements within the nanotechnology product and process innovations landscape distinguished through time series analysis of literature. Based on these studies, there has not been any study conducted to look into whether government initiatives can work out the inadequacies in nanotechnology research and commercialization. Figure 2.16 display a time series review of core referred journals articles in the area of nanotechnology product and process innovations (1934 - 2012).

Figure 2.15 Elements of Nanotechnology Product and Process Innovations



Source: Author's Design

Figure 2.16 Time Series Review of Core Referred Journals Articles in the Area of Nanotechnology Product and Process Innovations (1934 - 2012)



Source: Author's Design

2.7 Nanotechnology Policy of Emerging vs. Established Economies

Aspects such as economic, social, environmental, legal and ethical risks are among the several factors that necessitate the participatory involvement of national governments in various countries in regulating the creation, transfer and application of nanotechnology (Gokhberg et al, 2012). Policy implications suggest that albeit economic possibilities for nanotechnology is high, its introduction might lead to an ephemeral economic downturn and efforts should be taken to smooth the conversion to new nanotechnologies (Raesfeld et al, 2012). The nanotechnology turf proffers the likelihood of reforming the international S&T policy setting (in terms of commodities market, global production, value chains and the nature of scientific collaboration) as well as producing a momentous impact on the route of R&D for a wide-ranging nations and firms (Evan, 2008). Branson et al (2013) endorses that within the economic context, emerging technologies generally result in multiple effectual and consequential properties such as introduction of new markets, competitive industrial fluctuations, production locations, demand for labor and capital, repercussions ensuing from demand for skills, consequences for wages and employment and environment impact.

The initial occurrence of government support for nanotechnology began in the United States, regarded as a central investment and policy priority. Not only are innovations germane to developed countries, it is equally pertinent to developing countries as well (Walsh et al, 2002). China has also surfaced as a swift follower of nanotechnology and has recognized nanotechnology as a "priority mission area" and "key frontier technology" over the next 15 years. According to a survey conducted by Maclurcan (2005) on 62 countries, which supported a degree of nanotechnology activity, 18 out of 62 of them categorized as "transitional[35]" countries and 19 out of 62 of them categorized as "developing" countries. A further 16 countries demonstrated either individual or group research in nanotechnology (3 of which were categorized as "transitional" and 12 "developing"). An additional 14 countries have expressed interest in engaging in nanotechnology research (1 categorized as "transitional" and 13 "developing". Romig et al (2007) testifies that policy makers from various national and transnational innovation systems go all-out to draw policies to realize often highly ambitious promises often ensuing from the emergence of nanotechnology. However, Evan (2008) points out that owing to the extensive effect of nanotechnology on myriad disciplinary areas, hence research governing institutions will channel their research only towards certain areas of specialization (finding the right application to focus on and identifying their potential fields (Wonglimpiyarat, 2005)) depending on each respective country's pre – existing strengths[36].

According to Korea's National Nanotechnology Initiative (NNI) for example, Lee and Song (2007) states that high potential areas of nanotechnology that could vouch world level competitiveness will be selected and focused on. Salerno et al (2008) and Motoyama and Eisler (2011) highlight that almost every country in the world has chosen to invest significantly in nanotechnology. Wang and Shapira (2011) lay support to the fact that by 2008, over 60 countries pronounced the launch of huge scale public support programs for nanotechnology. Romig et al (2007) exemplifies China and India who are making strenuous efforts to advance in nanotechnology but partially crippled by the escalating difficulty attributable to forceful competition and the requirement for a high scale of technical

[35] Transitional countries are the countries of Central and Eastern Europe and the Former Soviet Union emerging from the social type command economy towards to the market economy; whereas "Developing countries" are countries that are in the process of becoming industrialized. Average national income must be below $9,265 for a country to be classified as a developing country (Galina, 2009).
[36] In developing economies like India, value the promise of nanotechnology for infrastructural development in particular. The area of energy storage, improved efficiency of solar cells using nanotechnology has been a prime area of research in many large emerging economies (S. Walsh, D. Huzzy, R. Burke, R. Boylan, 1999).

superiority. According to Meyer & Persson (1998), countries follow different patterns of collaboration, whereby some countries selectively establish bilateral relations and while others collaborate with large number of nations. This finding revealed through a co-authorship analysis, whereby results were displayed in the form of a co-authorship matrix. Evan (2008) reported that countries like India have also embarked on leveraging its efforts with international partners, developing bilateral cooperative agreements with more advanced nanotech nations such as the European Union, Germany, Italy and Taiwan. Project for Emerging Nanotechnologies (PEN) corroborates this by highlighting that India currently has a three-way partnership with Brazil and South Africa to link each country's nanotech efforts and fund targeted research areas that include advanced materials, healthcare, clean water and energy.

Corbett et al (2000) concludes that the high cost of setting up nanotechnology R&D programs will severely limit activities in developing countries, for the near future. However, the financial resources set to invest in nanotechnology research in many Asian countries in particular (developing countries) illustrate an increased level of commitment by local governments towards the nano - revolution (Wonglimpiyarat, 2005). While scores of policies have been set in place in the development of nanotechnology all over the world; however, based on the existing literature, it is palpable that there are further pertinent issues that have not been dealt upon en-route to future policy directions in the field of nanotechnology. Helland and Kastenholtz (2008) state that the research of the link between sustainability and nanotechnology is still quite in the beginning. Rinkel (2012) asserts that as S&T become more central to economic development, the question of future-oriented governance of emerging technologies gets raised repeatedly. Through the evolving field of nanoscience and nanotechnology (N&N), Fonseca and Pereira (2014) point out that, while innovative governing regimes have been introduced to support the development of innovative nano transitions, and its corresponding economic benefits, the core of the regime pursuits towards "responsible" nanotechnology development, and ensuring that the concerns of different stakeholders within the upstream processes of the innovation system, have been duly addressed by social scientists; and as Delgado-Ramos (2014) clearly state, in order to acknowledge the high degree of uncertainty hailing from the potentially-risky nano innovations.

For instance, Bowman and Hodge (2006) had stated that the US and Japanese governments, being the biggest investors of nanotechnology have neglected to implement nano-specific regulatory arrangements and have chosen to regulate its implementations through existing statutory measures, which are not explicitly appropriate for classification of nanotechnology. In terms of critically addressing the area of sustainable nanotechnology innovation, Foley and Wiek (2014) concludes that the size of public funding and support; risk mitigating capabilities; and the the social, ethical, legal and civic dimensions are constraining factors.

Table 2.2 provides a list of status extracts of nanotechnology development and policies of emerging and established countries. Out of all these extracts 2.1 – 2.9, except for United Kingdom' negative impact assessment of nanotechnology policy towards the nation, there have not been any reports that provided evidence of the impact of nanotechnology policy in other countries; as to whether or not it has positively contributed to the enrichment of the nation or augmented economic growth.

Table 2.2 Status Extracts of Nanotechnology Development & Policy of Emerging and Established Countries

Country	Country Development	Source
Australia	As of 2008, Australia's nanotechnology policy is still in its infancy and lags international research in the field. In 2007, there were 75 nanotechnology research organizations, including research institutions, universities, Cooperative Research Centres (CRCs), ARC Centres of Excellence (CoE), Australian Nuclear Science and Technology Organization (ANSTO) and the CSIRO and approximately 80 nanotechnology companies. In 2009, as part of the nano innovation agenda, the government announced the establishment of the National Enabling Technologies Strategy (NETS) whereby significant investments have been made in nanotechnology research through the Australian Research Council (ARC) and Commonwealth Scientific and Industrial Research Organization (CSRIO).	Australian Academy of Science (2009) Nanotechnology in Australia; Harwood, Jeffrey and Schibeci, Renato (2008)
China	Government efforts in nanotechnology have reached further into the commercial end of the value chain. Their substantial investment in nanotechnology – of the four "science megaprojects" under the Medium and Long term plan (for high technology) has paid large dividends at the research stage but has yet to result in significant commercial payoff.	Appelbaum, Parker, Ridge and Motoyama (2010)
India	Nanotechnology in India is a public driven initiative and industry participation is still at a nascent stage. Government agencies provide major funding for nanotechnology R&D. Although private sector is exploring the opportunities in nanotechnology, its expenditure is very small. In terms of investment in nanotechnology, India lags behind countries like China. However, several CoEs have been established to develop either nanoscience research or to take on the development of applications in various spheres.	International Development Research Centre Canada (2009)
Japan	Japanese nanotechnology is in involved in semiconductor processing (nanostructures) and micro machines. Nanotechnology in Japan refers to the construction of nanostructures on semiconductors and other inorganic surfaces. Mainly the government and businesses investigating future technology for computers drive the semiconductor-inorganic efforts. Japan is also seeing the rapid development of equipment for use at the nanometre level (STMs and AFMs) and its integration into the research laboratory. Manufacturers like Fujitsu, Hitachi, Matsushita Electric, Mitsubishi Electric, NEC, Oki, Sanyo, Sharp, Sony, Toray, Mitsui and Toshiba have invested in nanotechnology research.	Sienko. T (2010) Present Status of Japanese Nanotechnology Efforts
Korea	Government launched the Korean Nanotechnology Initiative (KNI) in 2001. The first phase of the master plan spanned from 2001 – 2005. The 1st phase focused on creating infrastructure for nanotechnology R&D. The 2nd phase of the master plan is spanning from 2006 – 2015 and focused on laying the foundation for industrialization. During the 2nd phase, R&D investment increased and investment for infrastructure decreased. Since 2005, Korea is currently ranked fourth (4th) in terms of nanotechnology competitiveness.	Ministry of Education, Science and Technology: Nanotechnology for Dynamic Korea, Korea Nanotechnology Research Society)
Singapore	Economic Review Committee has identified nanotechnology as one of the key areas for Singapore's pursuits of competitive advantages. There are around five (5) companies, which are involved in nanotechnology R&D and business. The Singapore Economic Development Board is the funding agency supporting industry applications R&D particularly funding nano start-ups and international joint ventures.	Asia Pacific Nanotech Weekly (2003)
Thailand	The country's nanotechnology development is far behind other countries – 10 years at least. The National Nanotechnology Centre (Nanotech) has set up 7 associate centres in universities nationwide with about 400 researchers in total. The strategic plan aims for 100 per year until 2013. The centre has so far awarded 100 scholarships to students to study PhD overseas.	SciDevNet (2010) Thailand Nanotech Makes Ahead
United Kingdom	The National Nanotechnology Initiative initiated in 1986. UK was recognized to be ahead of other countries when the nanotechnology research program started in the mid – 1980s. However, several government reports have reported that the Department of Trade and Industry (DTI) and scientific community lacked the foresight to drive the technology forward. Commercialization of nanotechnology research is the UK has been dismal. There have not been any reports to justify any improvement since.	House of Commons Science and Technology (2004)
United States	The US has been the first countries to recognize the potential of nanotechnology and to establish R&D funding for nanotechnology. Initial support for nanotechnology R&D dates back to 1980s. With the establishment of NNI in 2000, federal investment in nanotechnology has been coordinated. R&D funding has increased greatly since then.	P. Shapira and J. Wang (2007)

In the case of the US-NNI, Motoyama, Applebaum and Parker (2011) clarify that the bulk of the federal government fund was channelled into universities and government labs and little into the private sector, because the federal government had justified its intervention by claiming that the private sector is unable to commit to the long-term investments required for a broad, complex, expensive and risky nanotechnology. According to Motoyama, Applebaum and Parker (2011), NNI has been successful in funding university research[37], but its implementation has not been successful in channelling funding towards private sector commercialization, since its decade long establishment. Three years later, through a difference-to-difference analysis, Hyun and Jeongsik (2014) has revealed that after the NNI, U.S universities have significantly increased knowledge inflows from the industry, reduced the branching out to novel technologies, narrowed down the research scope and become less likely to generate technological breakthrough outcomes in nanotechnology, as compared to other US and non-US institutions. There has been a vast contrast in the status of outcome compared to Shapira and Wang (2007) and these new evidential outcomes have been clearly inconsistent with the NNI objectives. Table 2.13 is the summarized review of governmental reports on nanotechnology in terms of research methodologies used, results and conclusions.

2.7 R&D Management

Marieno (2003) paper attempted to study the innovatory phenomena at the micro and macro level, incongruously did not indicate or mention the term R&D management in the entire text of the paper, even though it has been made absolutely palpable in the main title of the

[37] Walsh and Ridge (2012) demonstrates that US doctoral research on nanoscale phenomena has experienced meteoric growth during the last decade and the volume and rate of graduate research papers to be positively correlated with federal funding. Moreover, Walsh and Ridge (2012) state that the expansion has been uneven and disproportionately concentrated within leading US research universities and regions with significant research and technical infrastructures.

paper. Following suit are Li and Kozhikode (2009) who have discussed in their paper, which is supposedly to be the implication for global R&D management, without enunciating the term R&D management in their entire text. Nobelius (2004) had identified five (5) earlier R&D management generations ranging from 1950s to the 1990s.

Nobelius (2004) has exemplified the Bluetooth case study, as moving towards the sixth generation of R&D management. The author professes that many companies constitute a mixture of approaches depending on various factors and consequences, which does not rigidly follow a single generation religiously. The author admits that R&D management is a formidable and arduous task. Prajogo and Sohal (2006) have liberally, without any reference to any closely relatable conventional authority have placed technology management and R&D management as one and have compared them to total quality management.

Thus, it is greatly reassuring that Jayawarna and Holt (2009) have compared both studies by Miller (1995) and Francis (1992) to predominantly arrive at a juncture to state that the distance between quality management and R&D management is narrowing as a result of overlapping and intersecting interests. The analysis made by Jayawarna and Holt (2009) on both studies unveils the possibility for this mutual intersection to shape and fortify a newer and more substantial definition for the term R&D management. Miller (1995), Francis (1992) and Jayawarna and Holt (2009) may not have prescribed an explicit definition for R&D management but have somewhat indirectly contributed towards the regurgitation of promising prospects towards the shrinking gap between quality management and R&D management.

Table 2.13 Review of Government Reports on Nanotechnology R&D and Commercialization

No	Journal Title/Report	Research Methodology	Findings and Results	Suggestions/Conclusions
1	Nanotechnology Development in Malaysia: Industrialization Strategy and Practices Uda Hashim; Elley Nadia; Shahrir Salleh (2009) - Int. J. Nanoelectronics and Materials 2 No 1 (2009) 119 – 134	Review of literature: - Experiences in industrial collaboration observations - University Malaysia Perlis (UNIMAP) involvement in Nanotechnology	Strengths, Weaknesses, Opportunities and Threats (SWOT) General Analysis by MIGHT for EPU Recent Developments in Nanotechnology: - Establishment of Nanotech Equipment/Research Centres - Journal Publications/Seminars - Postgraduates students in Nanotechnology (Yearly Statistics Not Provided) Nanotechnology Activities (examples of projects conducted) by Institutes/Organizations in Malaysia: - Material and Manufacturing - Nanoelectronic and Computer Technology - Life Sciences/Medicine & Health Actions implemented by MOSTI: - Incorporation of nanotechnology as national priority in 9th MP - Establishment of National Nanotechnology Centre (NNC) & Key Actions	Specific conclusion not provided
2	Challenges and Issues with Nanotechnology at the Product Development Stage Tetsuya Kirihata (2008) - Vol. 5 No. 2 (2008) 65 - 71	Conducted a questionnaire survey mainly to those nanotechnology related companies who participated in the Osaka Science and Technology Centre's Kansai Nanotechnology Promotion Conference - 329 questionnaires sent beginning Dec 2003 and	88/132 indicated that they were working on nanotechnology commercialization - 54/88 were listed companies - 34/88 were unlisted companies ~ 70% of companies revealed some difficulties in the product development stage Major Causes of Difficulties: Extracting visions and conceptualizing market needs (HIGHEST: 58.3%); Funding (SECOND HIGHEST:	Nanotechnology businesses are unable to cover the cost of R&D and commercialization The tendency is probably due to the expensive equipment needed for nanotechnology commercialization

		collected in Jan 2004 - 132/329 valid responses received ********************** *Questions were identical to those conducted by Inoue et al (2003) whereby:* - *Questionnaires were sent to 3626 manufacturing listed companies* - *491/3626 listed companies responded*	41.7%) Focusing on Manufacturing Industry: Funding (2x higher than the result of Inoue et al) External Collaboration (3x higher than the result of Inoue et al) Focusing on Listed Companies: Funding and External Collaboration was ~2x higher than the result of Inoue et al) There is a tendency for a % of R&D expenditures in nanotechnology based businesses t to exceed other businesses Source of funding for R&D was derived from government or municipalities; followed by funding from own businesses not connected with nanotechnology; followed by sales from nanotechnology business itself ~ 80% of respondents replied that external collaboration is very necessary >80% already collaborate with universities and institutions >80% replied that top down management is very necessary in product development stage (results < than Inoue) >90% replied that describing market needs is very necessary	Companies engaging in nanotechnology are more enthusiastic in collaborating with other industries. Universities/institutions Nanotechnology companies seem to emphasize the development of products based on market needs throughout the R&D phase Important to identify the challenges and issues within the nanotechnology businesses also in basic research and commercialization stage (not only product development) Suggestions Improvement of flexibility in public funding as high priority policy National government and local municipalities to establish public policies to assist start-ups firms that can support nanotechnology ventures R&D assistance systems targeting SMEs An interdisciplinary approach can be an advantage and collaboration with different fields and businesses are essential for innovative product development
3	CRS Report for Congress Nanotechnology and U.S. Competitiveness: Issues and Options (May 15 2008) - Science and	Review of Literature Quantitative Analysis - Research and Development Investments (Public and Private	United States' National Nanotechnology Initiative (NNI) and its activities U.S Competitiveness Indicators - There hasn't been any data to assess	Thorough assessment of measuring the competitive position of the United States in regards to nanotechnology is not possible. Nevertheless, many experts believe

	Technology Policy Resources, Science and Industry Division	Sector Investments) - Quantity of Peered Reviewed Scientific papers and Outputs/Citations to Peer Reviewed Papers; Papers in "HIGH IMPACT" journals - Patents	nanotechnology and the US Government does not collect data such as revenues, market share and trade (indicators used to measure competitiveness of nanotechnology industries) - Following the creation of NNI in the year 2000, more than 60 nations have established their own national nanotechnology initiatives - A business leader survey accounted that 63% believed that the United States is leading other countries in nanotechnology R&D and commercialization - In the absence of comprehensive output data, indicators such as public and private research investment inputs and non-financial (scientific papers and patents) are being used to measure the United States competitive position in nanotechnology - Information derived from basic research is available to all competitors and therefore does not provide a competitive advantage to the United States - National research and development investment is an input measure to translate R&D results into commercial products guaranteed there is capability of scientists and engineers conducting the R&D - US based companies may conduct production and other work outside of the United States - US educated foreign students may return home to conduct research and create new businesses	that United States still remains the global leader in nanotechnology Public and private research investment inputs and non-financial (scientific papers and patents) may not prove to be reliable indicators because basic research in nanotechnology may not translate into viable commercial application since basic research can take decades to result in commercial applications and scientific understanding may not provide commercial opportunities

			- SMEs may lack the resources needed to bring their nanotechnology innovations to market - US Companies with leading edge nanotechnology capabilities and intellectual property may be acquired by their foreign competitors - US policies may impede nanotechnology commercialization making it unaffordable and less attractive than foreign alternatives - Comparisons of aggregate national data may be misleading	
4	RISKS: Lloyds Emerging Risks Team Report (2007) Nanotechnology Recent Developments, Risks and opportunities	Review of Literature Quantitative Analysis (Market research conducted by Lux Research(2006)) - 2005 Government spending in Western Europe, Asia, North America & Rest of the World - 2005 Corporate Spending in Western Europe, Asia, North America & Rest of the World - Products that use nanotechnology Case Study: Du Pont Case Study: Refnano Project	Hazard to Humans - Carbon Nanotubes are potentially toxic to Humans • Damage caused by inhalation of nanoparticles • Damage caused by ingestion of nanoparticles • Damage caused by absorption through skin - There remains no virtually no data on the potential negative impacts of nanomaterials on the environment (Royal Society (2005)) - Nano remidiation Hazards to Aquatic Life Accumulation to the Environment Direct benefits to Insurance & Possible Scenarios Regulation	Research on the ecotoxicology is urgently required Insurers will need to keep pace with this technology Insurers need to collaborate with universities Lack of regulation Consider the cost of product recalls including any D&O claims If exposures are large, the potential costs may feature in capital requirement calculations and when deciding on terms and conditions and pricing

			• Europe, USA, Japan	
5	Nanotechnology Commercialization Best Practices Anthony Waitz; Wasiq Bukhari (2003) Nanotechnology in Europe – Ensuring the EU Competes Effectively on the world Stage - Del Stark (2007) - Survey and Workshop organized by Nanoforum in Dusseldorf, Germany (21 June 2007)	Observations (in the form of survey) of the key factors for success in technology commercialization in nanotechnology Observing the different phases of the life of a nanotechnology start-up - First focus Issues that are specific to nanotechnology start-ups - Second Focus Issues relevant to all nanotechnology commercialization Using examples from both pure nanotech start-ups and other small-tech start-ups - Case Study: Nanosys - Case Study: MEMS CAD - Case Study: Nanomix	Phases of nanotech start-ups - Inception (How are they formed) ✓ Licensing Intellectual Property (IP protection) • Many start-ups in nanotechnology get at least their initial IP from universities or government labs. • Universities have offices that focus on the commercialization of their locally generated IP. • Nanosys has licensed IP from the following universities: Columbia, Harvard, LBL, MIT, UCLA, UC Berkeley, and Hebrew University • STUDY[38]: 70% of university inventions can't be utilized without the involvement of the inventor - Axon Technology Corporation was formed with IP from Arizona State University and the professor who generated the IP is still involved with the company ✓ Spinouts (formed by a parent company) MEMS CAD's spin out was RF MEMS to create WiSpry	IP is a central issue for every nano-start-up. Success Factor - Strong IP is a success factor Therefore labor costs required to develop nano IP is HIGH (because it requires different areas of science) - Good business plan - Well balanced team Pitfall - Platform technologies cause lack of focus - Failing to plan for progress Success Factor In Gov. funding -> Writing a good proposal that satisfies the soliciting agency's requirements is a success factor.

38 "Grilichesian Breakthroughs: Inventions of Methods of Inventing and Firm Entry in Nanotechnology", Michael Darby and Lynne Zucker, National Bureau of Economic Research, July 2003

		Observing different business models	✓ Independent entrepreneur - Funding • Friends and family, VCs, government, and corporate partners. - Growth - Exit IP Licensing, Product and service models	Having "luminaries" involved with the company Success Factor Having strong market knowledge Pitfall Transition from academic lab to commercialization Conclusion Like all technology start-ups, majority of nanotech start-ups will NOT be successful
6	The Economic Development of Nanotechnology – An Indicator based Analysis - Angela Hullmann (2006) - European Commission, DG Research, Unit Nano S&T: Convergent Science and Technologies Predecessor Publications	Analysis (using economic data) of Europe compared to its main competitors (US, Japan, India, China, Russia) - Analysing market data estimates • Selected forecasts from different studies	- World market forecasts for nanotechnology in billion US Dollar (Different sources[39]) • Commonality among sources: → Substantial increase of the market for nanotech products from 2001 -2010 → Exponential growth will begin in 2010 →Data not adequate for deeper analyses - World market 1999-2003 and forecasts for 2015 in US $ billion →All areas expected to increase	- Empirical analysis of the economic development of nanotechnology starts with the market prospects (due to real facts are not easy to measure and almost impossible to prospect) - Impact on the number of jobs - in the manufacturing industries - Many of these nanotech companies will work in sectors where company - Size is less important for research and development (R&D),

[39] The forecasts originated from the following sources: German Government, Evolution Capital, NSF 2001, Evolution Capital 2001, Sal. Oppenheim 2001, DG Bank 2001, DTI 2001, US Nanobusiness Alliance 2001, Cientifica 2002, In Realis 2002, Mitsubishi Research Institute 2002, Deutsche Bank 2003, Nomura Research Institute 2003, BCC 2004, GEMZ corp. 2004, Helmut Kaiser Consultancy 2004, Lux Research 200

	- "Some figures about nanotechnology R&D in Europe and beyond" (1st publication; December 2005) - "Results of the informal collection of inputs for nanotechnology R&D in the field of (eco)toxicology" (2nd publication; June 2006)		→ Nanodevices and nanobiotech estimated to have largest share (415-420 mil US$) →Materials (50 mil – 145 mil US$) By 2015 →Materials (145 mil – 340 bill US$) →Followed by pharmaceuticals, chemical processing, aerospace - World market forecasts in different nanotechnology segments → Overall average increase of 15% annually →Not a real breakthrough - Volume and world market share of the nano-enabled drug delivery market → Avg. annual increase of 50% (2005-2012) → Market share increase to 7% in 2015 → Market share increase to 10% in 2020 - Global sales of products incorporating emerging nanotechnology by region - forecast in percent → Asia/Pacific Region – most important region for sales →USA-Decreasing until 2008 →Europe-Small/continuous increase of share →NEAR FUTURE: Products coming from strong Asian markets will dominate the world market	production or marketing. Risk capital for nanotech start- up companies is available. In Europe, the private investors are lagging behind the public funding agencies (the European nanotech research has to suffer from lower private funding sources) • Lack of commitment of European private investors - United States and Japan have a more balanced partition of private and public funding - High level of public funding of nanotechnology will have a positive impact on the S&T excellence of Europe. - Knowledge and - Intellectual Property are greatly publicly funded. - Potential dangers of nanoparticles addressed through contributions of research activities on the topic. - Political action needed if risks turn out to be socially unacceptably high. - Require well educated nanotech workers and researchers and world - wide competitive infrastructure for knowledge

			→AFTER 2008: Pharmaceuticals will become stronger (dominated by US economies) - Estimated worldwide public funding, in 1000€, for nanotechnology R&D in 2004 by individual countries Japan →2/3 total funding = private funding Europe→1/3 total funding = private funding US →54% private funding Europe is lagging behind in public funding - Estimated public and private funding for nanotechnology R&D in 2004 by world regions in million € - Venture Capital funding worldwide by application and by year, in million US$ - Venture Capital funding worldwide in nano, in absolute numbers and as share → Nano-biotechnology is most attractive for VCs - Number of nanotechnology jobs in million and the share of nanotechnology jobs of all manufacturing jobs in percent →Lux Research expects 10 million of manufacturing jobs in nanotech by 2014 →Many of the jobs will be created in SMEs - Nanotech Companies worldwide: decades and years (1981-2005) of creation →Most active companies in terms of size	production

			are from: • US • Germany • UK - Companies worldwide in different nanotechnology segments and in most active countries - Nanotechnology companies in leading countries and by company size (turnover in US$ million) in most active countries (1100 is the dataset) →460/1100 = SMEs →390/1100 = Research Institutes →120/1100 = Large Companies →80/1100 = Subsidiaries/Joint Ventures - Nano-technological institutions by country and by type of organization - European institutions (university and other research institutes, companies) active in nanotechnology - Nanotech patents worldwide →Exponential growth in 1999 and 2002 - Average annual growth rates (%) per nanotechnology subfield for two periods: 1995-1999, 1999-2003 →Average growth rate is 14% from 1995-2003 - Patents worldwide according to applicant and inventor countries - Top 10 patenting countries worldwide in	

			each nanotech field, 2003 - Nanotech patents in top 8 applicant countries - Average annual growth rates of nanotech patents for in 2003 →Highest no of nanotech patents come from US - Scientific publications in nanotechnology in SCI database per world region, 1992-1995 and 1998-2001 - Scientific publications in nanoscience per country and subfield, 1999-2004 - Number of nanotechnology publications and citations in the SCI database 1991-2000 for top 25 cited countries, ranked by average cites per paper →Most active is US = 18000 Nano scientific publications (1999-2004); followed by Japan and China by a large difference - World market forecasts for different nanotechnology subareas and applications in US$ million	
7	Innovation in Nanotechnology- An Asia Pacific Perspective (2009) Proceedings and Papers presented at the consultative workshop on promoting innovation in nanotechnology	PAPER I: NANOTECHNOLOGY FOR DEVELOPMENT: A TECHNOLOGICAL AND SOCIAL PERSPECTIVE - Identification of core areas by	PAPER I: NANOTECHNOLOGY FOR DEVELOPMENT: A TECHNOLOGICAL AND SOCIAL PERSPECTIVE Identified core areas: • Nano-biotechnology	PAPER I: NANOTECHNOLOGY FOR DEVELOPMENT: A TECHNOLOGICAL AND SOCIAL PERSPECTIVE Many developing nations are not in a position to be able to take advantage

	and fostering industrial application: An Asia Pacific Perspective	the World Bank 2009 where NSNT can make a major contribution *(Methodology not specified)* - Review of literature and reports (World Bank and workshops) Key Questions: ************ • What are the possibilities for the less technologically advanced nations in the Asia- Pacific region in terms of the "nanoscience and nanotechnology (NSNT)" wave that is now upon us? • What could and what should they be doing? PAPER II: NANOTECHNOLOGY AND ITS INDUSTRIAL APPLICATIONS: INTERNATIONAL, REGIONAL AND NATIONAL INITIATIVES • Review of literature and reports	• Safe drinking water • Strengthening food security • Health • Environmental protection • Energy Storage, production and conversion • Manufacturing Ethical Implications • fair distribution of benefits • scarce financial resources • lack of skills in developing nations • Issues of privacy Legal Issues • Intellectual property (IP) protection and licensing Environmental implications PAPER II: NANOTECHNOLOGY AND ITS INDUSTRIAL APPLICATIONS: INTERNATIONAL, REGIONAL AND NATIONAL INITIATIVES - Material Technologies - Health and Bio - Laser Technologies - Nanoelectronics - Nanofoods - Future Perspectives	of this technology The formation of South-South nanotechnology partnerships[40] could help in the eventual formation of North-South research and business alliances. Collaboration between NSNT researchers in the South and the sharing of their experiences and research infrastructure could help to find solutions to urgent problems faced by their societies Success in such collaborative initiatives could provide the foundation for commercializing research findings through both South-South and North-South partnerships PAPER II: NANOTECHNOLOGY AND ITS INDUSTRIAL APPLICATIONS: INTERNATIONAL, REGIONAL AND NATIONAL INITIATIVES Discussion: General view was that poor countries should stay with basic research on nanotechnology and buy technologies from developed countries.

[40] Sri Lanka has established the Sri Lanka Institute of Nanotechnology (SLINTEC), The Asian Institute of Technology in Bangkok has set up a Centre of Excellence in Nanotechnology (CoEN) and has commenced a postgraduate programme in nanotechnology in partnership with Thailand's Nanotechnology Centre (NANOTEC).

			Inter-Organization Programme for the Sound Management of Chemicals (IOMC) European activities in nanotechnology Hungarian activities in nanotechnology	**Conclusion was not provided*
8	Commercialization of Nanotechnology – Key Challenges, Tom Crowley (2007) Workshop organized by Nanoforum in Helsinki, Finland (29 March 2007)	Quantitative analyses of the economic development of nanotechnology in Europe (from various sources) - Private and public funding in Europe, USA and Japan in 2005 - Venture Capital investment in nanotechnology (2006 global breakdown – N. America, Europe, Rest of the World; 2006 Sectorial breakdown- Biotechnology, Semi-Conductors/Electronics, Other Sectors) Discussions and presentations at workshop Review of Literature/Papers/Public Sources	3 Areas of concerns are identified: i. Low proportion (only 3.5%) of global nanotechnology venture capital invested in Europe. ii. Despite public funding, Europe is lagging behind in the number of nanotechnology patents granted. (Public funding is at par with the US) iii. Industrial investment is only half that of the US	Causes of 3 Areas i. Low level of venture capital is due to a shortage of investment targets (lack focused business models; commercial experience and exit strategies) ii. Due to difficulty of identifying the commercial potential of research (because research is not aligned with industrial needs) iii. Due to obvious challenges like production scale up, health and safety concerns. Recommendations - Greater amount of funding need to come from the private sources - Industrial and consumer problems need to be resolved and fed back to research development - Funding priority to projects that address the 3 areas of concern (combine academic and industry participants)

				- Researchers to be incentivized to product patents & publications (and sharing the profits of licensing) - Universities should be able to rapidly assess the value of a potential patent. - Individual firms need to know what and with whom to integrate to provide the whole solution
9	Global nanotechnology research literature overview Ronald N. Kostoff, Raymond G. Koytcheff, Clifford G.Y. Lau (2007) Current Science, 92 (11), 10 June 2007	Text Mining was used to extract technical intelligence from the open source global nanotechnology and nanoscience research literature (SCI/SSCI databases) Extensive nanotech/nanoscience focused query (300 + terms) was applied Results were divided into (4) main sections: • Infrastructure • Technical Structure • Instrumentation • Application • Technical Structure - Document Clustering ❖ Divided into 256 thematic clusters using a clustering algorithm - Auto-correlation mapping - Factor Analysis	• Infrastructure - Country publication showed exponential growth from 1995 to 2005 (10 years) - Exponential growth contributed by China & South Korea ❖ China's researchers publishing a non negligible fraction of total papers in domestic low impact journals ❖ High impact journals by China →SMALL fraction but increasing ❖ From 1998 – 2002, China's ratio of high impact journals DOUBLED - In terms of aggregate nanotech research article production, USA remains the lead - In terms of papers containing nano-composites, China takes the lead; USA reduced over time from 1991 – 2005	

		- Cross-correlation mapping • Instrumentation - Atomic Force Microscopy Electron Microscope variants - Atomic force microscopy - Scanning tunnelling microscopy - Spectroscopy variants • Application - Medical - Non –medical (Factor Analysis)	- South Korea is second contender in total and highly cited papers • Technical Structure - USA produced most papers in 169 thrusts - China led in 70 thrusts - Japan led in 15 thrusts - India South Korea and Spain each led in 1 thrust • Instrumentation Study - China produced 25% more papers than USA - China's dominance was in atomic force microscopy - USA's dominance was in Atomic force microscopy • Application - USA led in non-medical publications; 6/9 themes in sensors, devices, lithography - China led in areas: catalysis, tribology, electrochemistry	

2.8 Missing Gaps

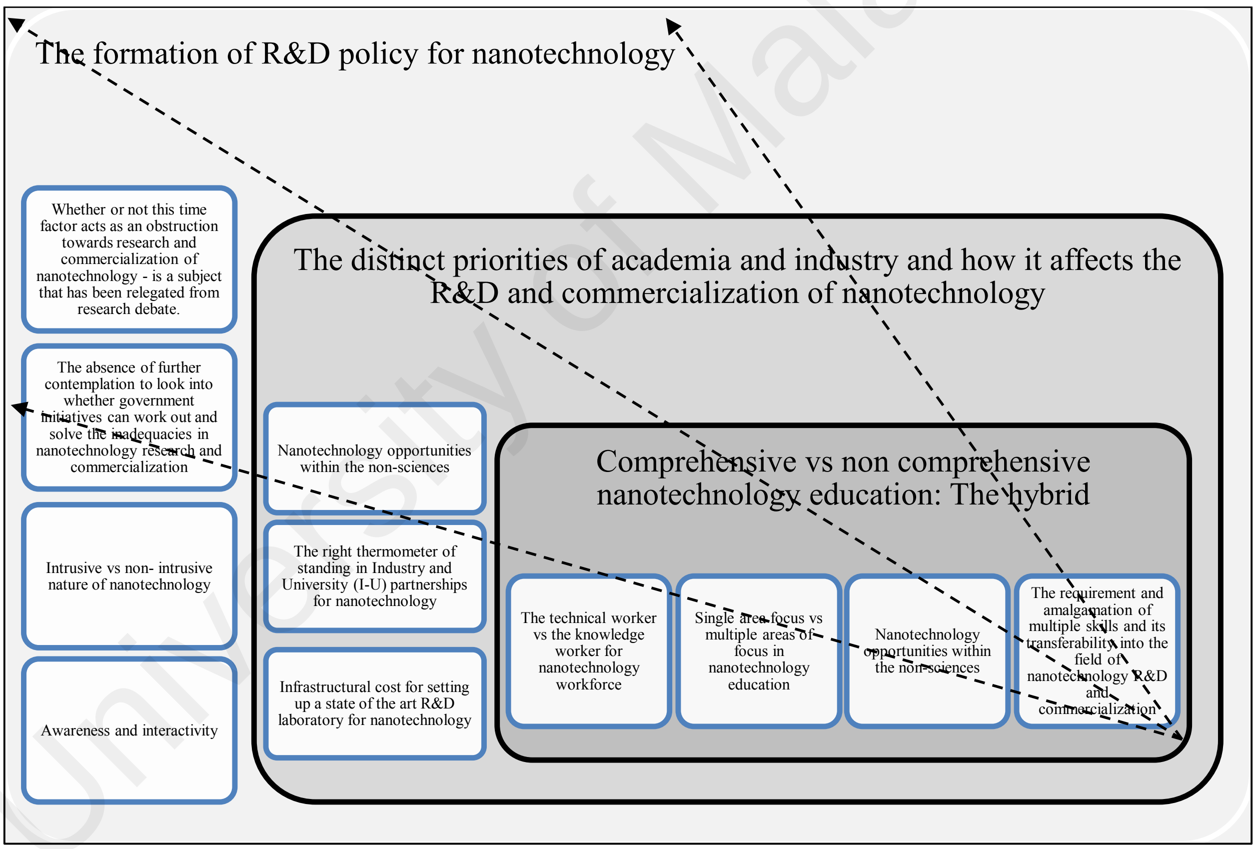
Figure 2.17 diagramatically explains the missing gaps in literature. The following missing gaps in three (3) main categories are as follows:

I: The hybrid of comprehensive vs non-comprehensive education of nanotechnology

II: The distinct priorities of academia and industry and how it affects the R&D and commercialization of nanotechnology

III: The formation of R&D policy for nanotechnology

Figure 2.17 Missing Gaps in Literature



Source: Author's Design

2.9 Summary

The identification of missing gaps steered the development and evolvement of 14 research themes through the identification of key factors in the process of showing meaning and connection within various themes of nanotechnology. These missing gaps along with researcher's ideas, triggered the formation of the conceptual framework and its associated building blocks. This chapter directs to the next following chapter which is Chapter 3: An Overview of Nanotechnology in Malaysia.

CHAPTER 3: An Overview of Nanotechnology in Malaysia

3.1 Introduction

The main objective of this chapter is to provide a comprehensive overview of the development of nanotechnology in Malaysia. Section 3.2 begins with a brief account on the beginnings of nanotechnology development efforts in Malaysia, which identifies our country's principal propellers of S&T particularly in nanotechnology, which has been significantly designated as a major thrust area. Section 3.3 will elucidate on the setting of university based research institutes and non-university based research institutes and their research application areas in relevance to nanotechnology. Section 3.4 briefly describes the current outputs of nanotechnology research in our country followed by Section 3.5, which analyses the Malaysia Plans (5^{th} until the 10^{th}) and also the past and present grants related to R&D in general and nanotechnology in particular.

3.2 Beginnings of Nanotechnology Development

The National Nanotechnology Initiative [41](NNI) made its debut in the year 2006. It is the country's nanotechnology plan that has been integrated into the Ninth Malaysian Plan (9MP) (2006-2010). Malaysia's NNI can be viewed upon as an avowal of the government's undertaking pledge to not only protract but to sustain nanotechnology in this country for an elongated period of time alongside other developing countries until the outgrowths of its efforts can be fully embraced and relished for the betterment of our country. The National Nanotechnology Directorate (NND) within the Ministry of Science, Technology and

[41] The establishment of Malaysia's NNI has resulted in the founding of the National Nanotech Centre (NNC), which will serve as a central coordinating platform for driving the government's nanotech policy and coordinating national R&D programs and infrastructure as well as liaison with industries to address business and economic issues. Malaysia's NNI aims to ensure that Malaysia will benefit from the advancement of nanotechnology related sciences by clustering and linking the resources and knowledge with Malaysia researchers, industry and government.

Innovation (MOSTI) is at the present entrusted to forefront the planning and development of the NNI. According to the Ministry of Science, Technology and Innovation (MOSTI), the Academy of Sciences Malaysia (ASM) is in addition the focal point for nanoscience and nanotechnology. Malaysia has also networked the National Nanotechnology Technical Committee together with SIRIM Berhad as the secretariat. Furthermore, Malaysia has been an active constituent of the Asia Nano Forum (ANF) since May 2004. It is Malaysia's aspiration to be one of the top ten nanotechnology nations that will transform the nation by creating new and innovative sources of economic growth for the hope of future generations. Nevertheless, this is easier said than done. It will take nothing but time-consuming yet relentless efforts for this ambitious aspiration to be converted into reality. Malaysia is still lagging behind in R&D infrastructure and human resource development compared to other members of Asia Nano Forum (ANF). The Malaysian Nano Forum (MNF) coordinates with ANF. ANF has led to the launching of Malaysia's National Nanotechnology Initiative (NNI).

3.3 Institutions and Research Centres in Pursuit towards Sustaining Nanotechnology in Malaysia

Within our local home country establishment, Malaysia heads the working assemblage on Nanotechnology Infrastructure and R&D. Public universities and public research institutes are primarily carrying out nanotechnology research in Malaysia. Except for International Medical University (IMU), there are no other private institutes or private universities conducting nanotechnology research (consisting of a nanotechnology research center) in Malaysia. In 2007, the Economic Planning Unit (EPU) performed a preliminary assessment (underpinning) study to identify the imminent R&D and applications of nanotechnology in Malaysia. In this study, six (6) nanotechnology national research centres (NNRCs) were identified. These NNRCs encompasses the Institute of Higher Learning (IHL) and Government Research Institutes (GRI). They were SIRIM Berhad, University Science Malaysia (USM), University Kebangsaan Malaysia (UKM), University Malaya (UM), University Putra Malaysia (UPM) and University Technology Mara (UTM). Joining this listing is the recent establishment of University Malaysia Perlis's Institute of Nanoelectronics Engineering. Malaysia's investment outlay towards R&D has summed up to RM124.3 M hitherto. Table 3.1 lists down the nanotechnology research centres in Malaysia and its corresponding applications and areas of research.

Table 3.1 Nanotechnology Institutions and Research Centres in Malaysia

Institute/University	Application/Area of Research	Background
Institute of Micro-engineering and Nanoelectronics (IMEN), UKM, Bangi	Nanoelectronics, OLED, Micro-electromechanical systems (MEMS/NEMS), Nanowire, Sensors	Set up in 2002. Consist of full time researchers, postgraduate students, PhD graduates, MSc graduates. Collaborating with institutions in Korea, Japan and Indonesia, Telekom and MIMOS. The Institute received an R&D grant of RM38.9M (approximately US$19.4M) from MOSTI in 2003.
Ibnu Sina Institute for Fundamental Science Studies (IIS), UTM, Johor	Nanochemistry – nanostructures material, nanocatalysts, CNT, nanoelectronic devices	Set up in 1997; other sources claim it was set up in 1971. Conducts fundamental science research. The Ibnu Sina Institute for fundamental Science Studies (IIS) within UTM has been identified as the leader for the National Nanochemistry Satellite laboratory. RM10 M (approximately US$2.6M was allocated in 2003 to further develop the centre by 2006.
Combinatorial Technology and Catalysis Research Centre (COMBICAT/NANOCEN),UM	Catalysts	COMBICAT received funding of RM15 M (approximately US$4M) from MOSTI in 2003 but there has not been any obvious transitions from research to successful commercial outputs, which are

		visible until today.
Advances Materials Research Centre (AMREC), SIRIM Berhad, Kedah	Nanomaterials and processes	Set up in Shah Alam in 1996; moved to Kedah in 2000
Advanced Materials and Nanotechnology Laboratory (AMNL), UPM, Serdang based in Institute of Advanced Technology, (ITMA), UPM, Serdang	Nano-composite materials, nanostructures, carbon nanotubes, Nanomedicine, Electronics	Set up in 1999
PutraCAT, UPM, Serdang	Nanostructures, nanoparticles of bulk metal oxides	Set up in 2008
Institute of Nanoelectronics Engineering (INEE), UniMAP, Perlis	Nanobiochips, photonics, non-volatile memory devices, novel devices, smart sensor	Set up in 2008
Malaysian Institute of Microelectronic Systems (MIMOS)	Nanostructures in MEMS/NEMS, nanoelectronics	Set up in 1985

Source: Asia Nano Forum (ANF); Institutions and Research Institutes Websites/ Organization Brochures

It is their applications and areas of interest (as stated in Table 3.1) that distinguish these institutions and research centres apart. The common and fundamental key goal of Malaysia's National Nanotechnology Initiative (NNI) is the fortification of world-class research institutions, expenditure on nanotechnology R&D, competitive business milieu, a robust education and training system, highly skilled and diverse workforce, efficient infrastructure, integrated involvement in nanotechnology activities, international cooperation and global network. These goals have not yet been attained and only certain efforts are consistently in progress. Although there is common linkage between basic research and the commercial development of nanotechnologies, Motoyama and Eisler (2011) proclaims that it is difficult to correlate the national efforts made in basic science with national economic productivity.

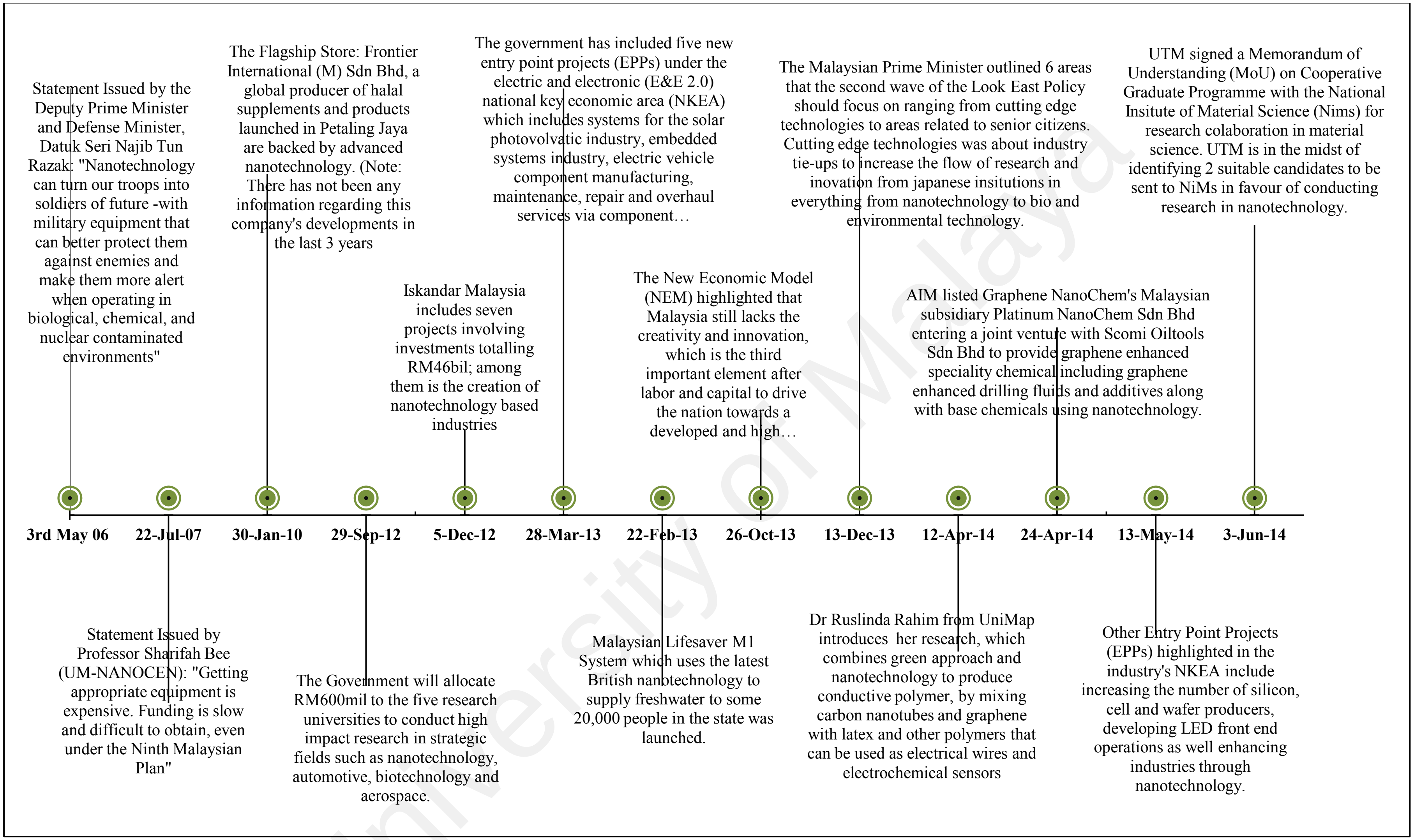
3.4 Outputs from Malaysia's Nanotechnology Research

Amongst the research outputs to date, one of Malaysia's utmost commendable nano product is Malaysian made aerogel; known as Maerogel by UTM. The maerogel is the cost effective, non-toxic and environmentally friendly raw material made from silica in rice husks, which produces high premium quality insulation material that can be applied to medicine and construction, among other areas. It has significantly resulted in 50 – 75 percent cost reduction and resembles that of frozen smoke. Traditional aerogel costs about RM15, 000 per kilogram (has existed approximately since 1931); whereas Malaysia can produce it for only RM5, 000 per kilo (News Straits Times, 28 Feb 2010). Maerogel has been patented in Malaysia and 22 other countries worldwide and is currently being commercialized through UTM's spinoff company known as Gelanggang Kencana Sdn. Bhd. This product was also chosen as the product of the year 2008 by the International Clean Energy Circle, United Kingdom. Another research output from Malaysia's nanotechnology research is nano-herbs by UniMAP. This is an herbal extract which is nano-sized and functionalized as Drug Delivery Systems (DDS) that serves as a medical treatment for brain cancer, brain healing, HIV, influenza H1N1, immunization improvement and bone healing. Nevertheless, there has not been a single piece of data to indicate that this product has been commercialized as yet. And its impact to society is yet to be acknowledged. Another research output from Malaysia's nanotechnology research is the biosensor kits by UniMAP. The function of these biosensor kits is to be able to perform halal product detection, early cancer detection and medical diagnostics. Nonetheless, there has not been a single piece of data to indicate that this product has been commercialized either. And its impact to society is yet to be recognized.

Apart from MOSTI, research centres and universities, it must be emphasized that there aren't many papers published in the area of nanotechnology in Malaysia. In addition to this, there is insufficient quantitative and qualitative data available concerning nanotechnology R&D. Furthermore, in comparison to the global distribution of nanotechnology literature which has grown dramatically over the years, it can be said that research literature on nanotechnology contributed by Malaysia remains bleak. There is also a strong deficiency of local expertise in nanotechnology in this country. From the market driven perspective, few sectors have been given precedence to jumpstart Malaysia's entry into the nanotechnology business. The sectors are: oil and gas, palm oil, electronics, ICT and agricultural food (Star, 1 Nov 2011).

Figure 3.1 displays a chronological timeline of nanotechnology developments in Malaysia from 2006 – 2014 as appeared in the The Star Newspaper from 2006 – 2014.

Figure 3.1 Chronological Timeline of Nanotechnology Developments in Malaysia (2006 – 2014)



Source: Author's Illustration based on The Star Newspaper (2006 – 2014)

3.5 Malaysia Plans and Industrial Master Plans

Since the Seventh Malaysia Plan (7MP), Malaysia has for decades trained scientists capable of contributing to the national development in S&T, where some pioneering work in nanotechnology were initiated. Current database (according to an unrevealed one source) indicates that there are about 150 local scientists directly involved in diverse areas of nanotechnology research. However, there has been neither any substantiation nor verification to confirm this statistic. The Intensification of Priority Research Areas (IRPA) program of the Eighth Malaysia Plan (2001 -2005) (8MP), which is governed and funded by MOSTI, identified nanotechnology as one of the 14 research priority areas, and is categorized under "Strategic Research" (SR). Table 3.2 shows the research categories and its allocations under IRPA. Within IRPA, Strategic Research receives an even distribution of 35% or RM 350 million of the total IRPA budget which was RM1 billion. That 35% distribution is divided into fourths over the five (5) year period between 2001 -2005, with nanotechnology and precision engineering as one of the four subcategories. Photonics, which could come under the category of nanotechnology and precision engineering or optical technology, saw an approved amount of RM 51.7 million. The SR projects are for a maximum period of 60 months, with potential for enhancing future competitive socio-economic development or new breakthroughs with commercial potential. Additionally, the projects must be multi-disciplinary, and have industrial linkages, with potential for commercialization.

Table 3.2 Research Categories and its Allocations under IRPA

Research Category	Allocation (%)	Priority Areas (% - Allocation)
Experimental Applied Research	30	Agriculture and Food Security Natural Resources and

		Environment Manufacturing and Services Social Transformation Knowledge Advancement
Prioritized Research	35	Manufacturing Plant Production and Primary Products Information and Communication Health Education and Training
Strategic Research	35	Design and Software Technology Nano-technology and Precision Engineering Specialty Fine Chemicals Technology Optical Technology

Source: MOSTI, 2001

In terms of R&D incentives, the IRPA apportions funding to public research institutions or public and private institutions of higher learning as well as to projects involving collaborations by these organizations with industry. The bulk of IRPA funding has been apportioned to activities that would lead to commercialization with some funding allocation offered to research activities intended for knowledge encroachment. As of 2006, IRPA grant currently supports three (3) nanotechnology programs and seventeen (17) projects with total funding of about RM 143 million (approximately US$37.6 million).

Other than IRPA, the Industry Research and Development Grant Scheme (IGS) funds companies with at least 51% Malaysian ownership in "Critical Technologies" which includes nanotechnology; whereas the Multimedia Super Corridor Research and Development Grant Scheme (MGS) allocates funds for private sector and MSC status companies related to nanotechnology R&D. The Demonstrator Application Grant Scheme (DAGS) funds for facilitating social economic progress of Malaysians via innovative use of different technology such as ICT and nanotechnology. For the Eighth (8^{th}) Malaysia Plan, the corresponding amounts in US$ are US$224M, US$62M, US$27M, and US$24M respectively. Table 3.3 shows the allocation of R&D grants from the Fifth (5^{th}) Malaysian Plan until the Tenth (10^{th}) Malaysia Plan. However, there was no specific numerical allocation indicated for R&D grants in the Ninth (9^{th}) and Tenth (10^{th}) Malaysia Plan. At the end of Eighth (8^{th}) Malaysia Plan, MOSTI has awarded about RM160M to nanotechnology related research projects. The inclusion of nanotechnology as a priority area under IRPA for Eight (8^{th}) and Ninth (9^{th}) MP is timely, and is poised to position the country in the long term to nurture a nanoscience research culture among researchers, and develop world class nanotechnology laboratories in Malaysia. During the Ninth Malaysia Plan (2006 – 2010), government funded RM 107M (US$35.26M) for nanotechnology. At present, nanotechnology has been emphasized in the development of the National Key Areas (NKEAs) under the Tenth Malaysia Plan (2011-2015). Under the more recent National Science and Technology Policy II (STPII) launched in 2003, nanotechnology was included in the strategy of building competence for specialization in key emerging technologies and identified as a key technology area to support the local industry.

Under STPII, the Malaysian government stated that its aims to augment its R&D spending to a minimum of 1.5% of GDP by 2010 and wants to achieve a minimum of 60 RSEs (Researchers, Scientists and Engineers) per 10,000 labor force (0.6%) by the same period. The interim (short – term) strategy of Malaysia is geared en-route towards identifying researchers in diverse areas of nanotechnology with specific proficiencies; raising the standards and equipping nanotechnology laboratories with high-tech facilities; and to plan a broad all-inclusive human resource development agenda for generating a large group of nanotechnologists. Nevertheless, this remains a strategy and not yet an accomplished actuality.

Table 3.3 Allocation of R&D grants (RM Million)

MP	IRPA	IGS	MGS	DAGS
5th Malaysia Plan	RM400 Million	NA	NA	NA
6th Malaysia Plan	RM600 Million	NA	NA	NA
7th Malaysia Plan	RM708 Million	RM100 Million	RM65 Million	RM30 Million
8th Malaysia Plan	RM833 Million	RM230 Million	RM100 Million	RM90 Million
9th Malaysia Plan	*IRPA, IGS, MGS and DAGS have been discontinued*			
10th Malaysia Plan				

Source: Five-year Malaysia Plans (various years)

However, it must be pointed out that during the Ninth Malaysia Plan (9th MP) and the Tenth Malaysia Plan (10th MP), IRPA, IGS, MGS and DAGS were discontinued. These grants have been replaced with the Science Fund, Techno Fund, Inno Fund and Nano Fund, which exist today. The per year allocation of these grants have not yet been disclosed to the public because the allocation disbursed was in sum totality and not specifically to a single grant. The allocation amount is subject to a quarterly or annual review of these grants. The quantum or the maximum amount approved for each grant is stated in Table 3.4. In the Industrial Master Plan (IMP3) that spans a 15 year period (2005 – 2020) is reported to recognize nanotechnology as a new emerging field. Malaysia's National budget 2006 unveiled the allocation of RM868 M to be provided by MOSTI for R&D. The focus will be in on biotechnology, nanotechnology, advanced manufacturing, advanced materials, ICT and alternative source of energy including solar, to promote innovation among local companies and new product development.

Table 3.4 Quantum approved for Science Fund, Techno Fund, Inno Fund and Nano Fund (After Eighth (8th) MP)

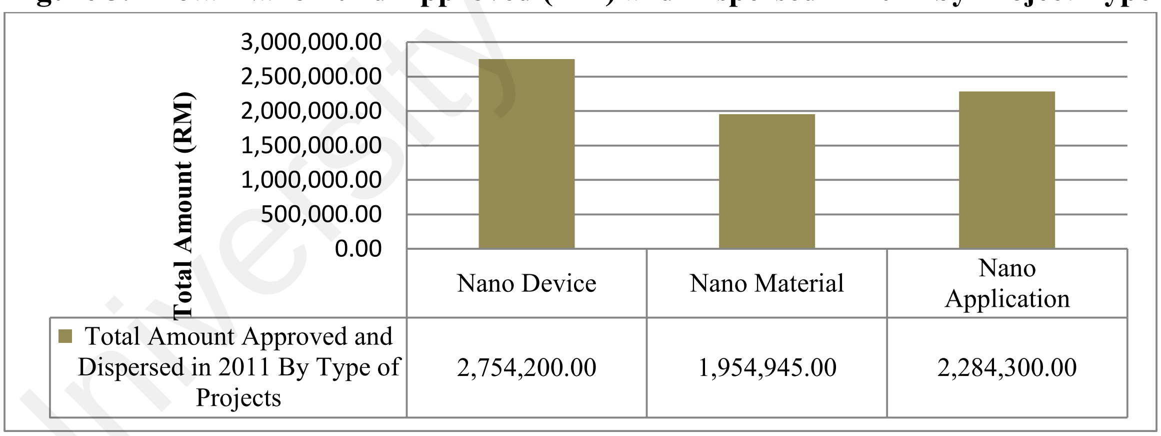
	Science Fund	Techno Fund	Inno Fund	Nano Fund
Quantum (Total Amount Approved)	Up to RM 1. 5 million	Between RM 1.5 million and RM 3 million	RM 50, 000 for individual/sole proprietary and RM 500, 000 for micro and small companies	So far, an average of RM200, 000 to RM500, 000 each were dispersed in 2011

Source: MOSTI (2011)

3.6 Nano Fund

Based on Figure 3.2, it is evident that the total amount of nano fund approved for nano devices oriented projects far exceeds the amount approved and dispersed for nano material and nano application oriented projects.

Figure 3.2 Total Nano Fund Approved (RM) and Dispersed in 2011 by Project Type

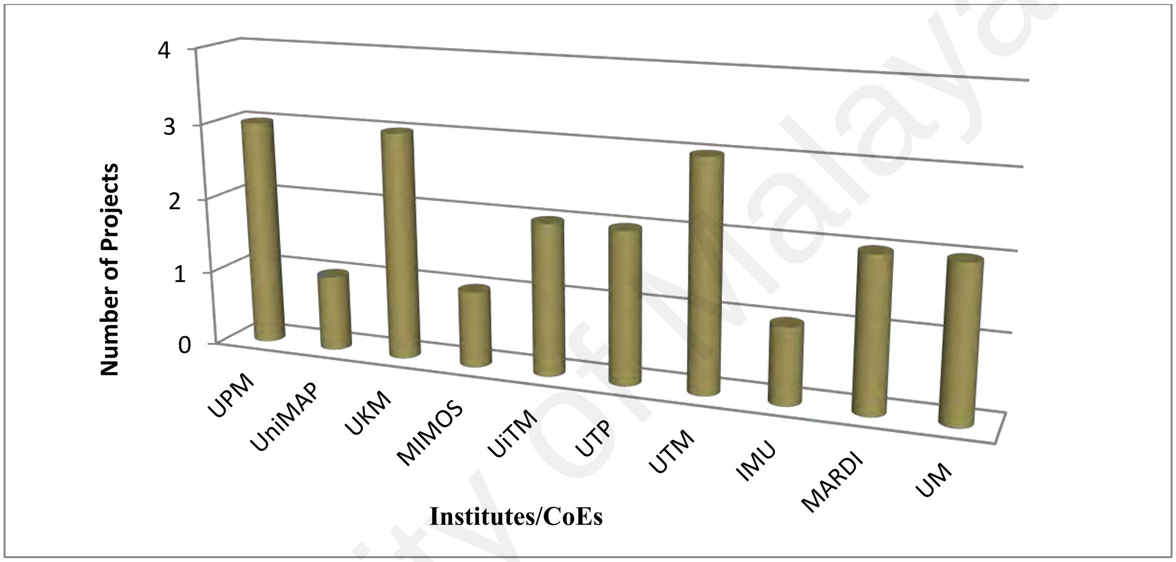


Source: National Nanotechnology Directorate, MOSTI (2013)

A total amount of nano fund approximating to RM7 M was given to twenty (20) nanotechnology projects in the year 2011. The 20 nanotechnology projects, which were approved, came from 10 institutes and Centre of Excellences (CoEs) in Malaysia as stated in Figure 3.3. The maximum number of projects approved (which were 3 nano projects) went to UPM, UKM and UTM; whereas a total of 1 – 2 nano projects approved went to

UniMAP, MIMOS, UiTM, UTP, IMU, MARDI and UM. Most of these projects began in 2011 and 2012 and is expected to complete at the end of 2013 and 2014. The trivial number of nano oriented lab projects that are being funded and conducted indicates that the current state of nanotechnology activity is in an inactive state.

Figure 3.3 Numbers of Nano Fund Projects Approved By Institutes/CoEs in Year 2011



Source: National Nanotechnology Directorate, MOSTI (2013)

3.7 Summary

It can be observed that there has been lot of activities that have been conducted by various universities/institutes/CoEs to coxswain the advancement and sustainability of nanotechnology in our country. Efforts have been boosting but the level of progressive outputs has been slow paced, resulting in the sluggish rate of infiltration of nanotechnology prototypes - products into the commercial arena. Even way before the NNI was initiated; many of these universities/institutes/CoEs have been granted hefty amounts of dough to assist in translating lab prototypes into full-fledged products. Even so, there seems to have been a lack of any visible and massive impact coming from these endowments. This chapter proceeds to the next chapter, which is Chapter 4: Research Methodology.

CHAPTER 4: Research Methodology

4.1 Introduction

The main objective of this chapter is to provide a multidimensional view of the research methodology administered in this study. This chapter begins with an explanation on the contextual investigation of thesis study followed by a brief explanation on how quantitative methodology was used to study the thesis problem statements. This chapter continues to explain how the systemic review of literature was carried out, followed by an explanation regarding data deficit, which served as a bottleneck, occurring during the preliminaries of this thesis study. This chapter continues to elucidate the synthesis of the research framework designed in order to dive deeper into the subject matter under investigation and bring to surface a solid depth of information that can serve as a platform for the diagnosis of barriers towards nanotechnology R&D and commercialization and flow of the data gathering process that entails the necessary steps towards the fulfilment of this thesis study, the sampling technique used in selecting the study sample, which explains the validation technique used to verify the reliability of data gathered for this study. This chapter also lists the sample distribution, designation and institutions.

4.2 Contextual Investigation of Thesis Study

Prior to embarking on the journey of exploring the barriers, that circumvent the commercialization of nanotechnology R&D, critical surface data was gathered and analysed to serve as a concrete basis of establishment for expanding the thesis topic to an advanced level of in-depth understanding. Surface data was required to position mark the preliminary standing of the status of nanotechnology based on existing and readily available information to validate the non-existence of advanced data, information and analysis from point of current insufficiencies as an indicator for justifying the need for further study towards thorough internalities of the subject matter. Surface data was not qualitatively driven but quantitatively driven based on statistical information generated from statistical organizations because it was crucial to substantiate the data through sources of preliminary thesis underpinnings as primary authentication. Problem statement analysis was subject to availability of these key data computed by these organizations. Personal census surveys would have been costly and would have required lots of funding. For instance, it is a challenge at present time to compute number of nanotechnology researchers in Malaysia from a wide array of scientific disciplines without properly instilling criteria levels to define who should be explicitly referred to as researchers in nanotechnology. One of the primary challenges for computing this data is the identification of priority scientific and core disciplines within sub disciplines in research projects to indicate the prioritized responsibilities of a lab researcher supposedly involved in the field of nanotechnology. This should be the role of census survey and a completely separate research project altogether. Since a problem statement can be identified by analysing available and present statistics on nanotechnology in Malaysia, it is important to note that there are statistical limitations. Statistical organizations in Malaysia do not compute nanotechnology statistics in a time series basis. These are important indicators, which requires census surveys carried out by statistical organizations like MOSTI and Department of Statistics (DOS) and is not possible for an individual thesis candidate to carry out, as it requires lots of funding. As of 2013, and according to officers in NND and MOSTI, there are no statistical reports published in the area of nanotechnology specifically. What is available are only the Science and Technology Indicator Reports.

4.3 Quantitative Study of Thesis Problem Statement

Statistics currently available from organizations entrusted to spearhead nanotechnology is scarcely. As a university candidate and the author of this thesis, the main responsibility was to communicate with these organizations formally and ethically through email and conduct formal visitations to their premises on appointment basis, where the latest information was periodically updated. Follow ups have been made via formal email and telephone. Nevertheless, statistics on nanotechnology concerning Malaysia is not widely available to the public and only certain high-level officers in NND or MOSTI are given restricted access to these statistics and it has to be requested formally. I have communicated with the highest officers in MOSTI and NND and their computed statistics are as what is stated in Chapter 1 and Chapter 3 of this thesis. Places like NND and MOSTI require security passes for access and no external person can access these doors anytime as required.

4.4 Systematic Review

Papers from 1989 – 2014 (26 year period: from the earliest to the most recent) were critically reviewed. Unique core subject themes identify each paper in various areas of nanotechnology. These core subject themes serve as an identification element to represent and denote each paper by author – title – year. The main emphasis of each paper's subject content was undetectable through title headings or key words from publications. Citation analysis (without the use of software) was conducted to demonstrate, how each paper is significantly associated to other scholar's works and has been depicted here through a graphical time series representation. Through this graphical representation, both citation connectivity and main elements of each paper's subject content enhanced the visibility of incremental literature development. This was to ensure that main themes highlighted in the review of literature, paved way for the identification of missing gaps in the area of nanotechnology, as shown in Chapter 2 and Chapter 4, through the author's design of conceptual framework and its building blocks. Through the connective flows established within the review of literature, key factors distinguished to reveal the evolvement of research subject streams and how these key factors relate to one other and how they developed to show meaning in various themes of nanotechnology. The key factors have been connectively represented and graphically illustrated, through the use of single and double arrow line connectors to indicate one way (independent) or two-way (interdependent) relationships.

4.5 Limitations: Statistical Data Deficit on Nanotechnology

Even though information on the potential uses of nanotechnology is immensely available, however, a comprehensive assessment of measuring the competitive position of the United States in regards to nanotechnology is unfeasible at this time. (CRS Report for Congress, 2008). Nevertheless, many experts have accepted the fact that United States remains a global leader in nanotechnology. Thus, there has not been any data collected (such as revenues, market share and trade) to assess nanotechnology. A matter of fact, there is no quantitative data on nanotechnology from any countries worldwide on time series basis sectorally. The only available indicators[42] are public and private research inputs, scientific papers and patents; however these may not prove (Motoyama and Eisler, 2011) to be unswerving indicators because basic research in nanotechnology may not translate into viable commercial application; in view of the fact that basic research can take decades to result in commercial applications and scientific understanding may not provide commercial opportunities.

[42] Gokhberg, L. et al (2012) clearly points out that manifold information sources do not solve the problem of attaining reliable and internationally comparable data on the economic scale; today, the value of nanotechnology is being derived from scientific publications and patenting in the absence of a harmonized framework for statistical data collection.

As Rouse (2012) clearly puts it that inventions often exist on "paper" and have not been fully realized in a laboratory setting. Nevertheless, national R&D investment in S&T is an input measure to translate R&D results into commercial products, guaranteed there is capability of scientists and engineers conducting the R&D.

Even though data for investment in national research and development is available; but until today, there is no statistical source that can vouch for the number of scientists[43] and engineers involved in nanotechnology globally. At the present time, there has not been any data on the number of student enrolments, number of degrees conferred in the area of nanotechnology in universities and colleges if any. Likewise, there has not been any data on the number of nano related job openings and corresponding wages existing to date. However, quantitatively through a text mining study (2003 – 2005), the number of scientific papers on nanotechnology and nanoscience contributed by each country has been statistically measured by Porter and Cunningham (2005), Kostoff, Koytcheff and Lau (2007), Kosumi and Nazrul Islam (2007;2010). Nevertheless, an unyielding challenge posed towards data anthology is due to its multidisciplinary nature which causes it to be borderless and therefore, Motoyama, Y. and Eisler, M. N (2011) affirms that international comparisons are even more problematic due to this reason.

Five (5) out of seven (7) published papers propose different delineations of the codified nanotechnology knowledge base (papers and patents) (Bozeman, et al, 2007). In Malaysia, the DOS and the MOSTI have not yet measured nanotechnology sectorally, regionally and

[43] Productivity is defined by statisticians using simple quantitative metrics such as the total number of scientists in a given nation and the total number of papers produced by individual scientists. There is no data yet available on the total number of scientists, researchers and engineers involved in nanotechnology in any nation until today. However, total number of publications related to nanotechnology is vastly available from various statistical sources.

nationally. MOSTI only recently set up its Directorate for Nanotechnology last year. Other countries like US, United Kingdom, Japan and South Korea too have not provided a sectorial measure of nanotechnology. Therefore, in the absence of these pertinent quantitative statistical data, a qualitative methodology proved to be the best approach towards gaining a thorough understanding and visualization of the subject matter under investigation.

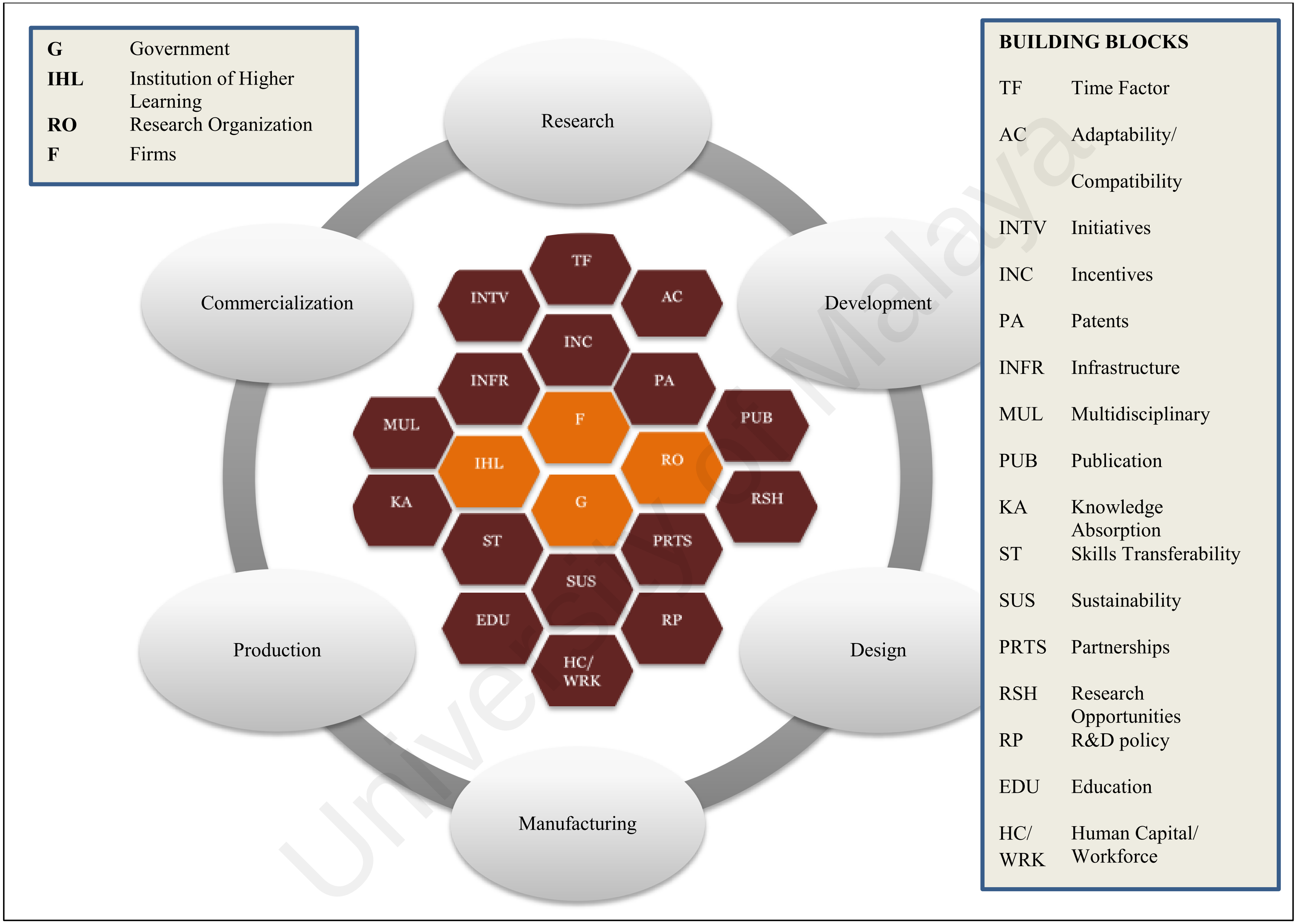
4.6 Synthesis of Conceptual Research Framework

The inner component of the framework shows the four (4) different players involved in the development of nanotechnology. These different players have been known to be engaged in various activities from research and development right up to commercialization. With regards to these pertinent activities, a total of 16 building blocks were identified to investigate the 14 research questions.

4.6.1 The Construction of Building Blocks

This section explains the design of the conceptual framework for this thesis through the formation of building blocks used as individual units of construction composed to formulate a larger subject entity that interoperate with interdependent units of construction. Building blocks have been clearly labelled and conceptual framework has been diagrammatically illustrated as shown in Figure 4.1. Missing gaps identified from critical analysis of literature along with the researcher's ideas triggered the formation of conceptual building blocks; ROs and RQs. Figure 4.1 consist of a list of building blocks belonging to more than one missing dimension (I, II and III) and not necessarily to a single missing dimension.

Figure 4.1 Conceptual Framework



(Source: Author's Design) Note: The research framework is to identify and serve as research guide to drive in the preparation of explicit exploratory and specific questions framework and not as an initial indicator to specify where each building block belongs to prior to data collection.

4.6.2 Constructive Build-Up from Missing Gaps, Primary RQs and Conceptual Building Blocks into the Formations of Broad Exploratory Questions and Focused Specific Questions

Following a deracination of missing gaps from a time series analysis of literature through a careful examination of distinctive themes and each paper's corresponding thematic research conclusions, the identification of primary RQs and the formation of fore-fronting building blocks to advance thesis purpose in order to meet research objectives were developed. Fore-fronting building blocks hailing from sub-divisions of inquiry extracted from in-depth literature scrutiny served as connecting nodes to extend primary RQs into broadened exploratory questions and later into focused specific questions.

Specific exploratory questions stated in Table 4.1 are a non-exhaustive list of questions, which were posed to the respondents. This qualitative method was conducted using an "open ended" approach whereby the questions were not worded in exactly the same way with each participant. As a researcher, I had the responsibility to respond and probe immediately to what the participants had to say by constructing subsequent questions to information the participants had provided. Questions were never given to the participants in advance. In other words, the interviews were conducted using an impromptu technique in order to evoke spontaneous and unanticipated results rather than rehearsed responses. The specific exploratory questions bifurcated into the development of different lines of questioning (same question subject but posed through a different angle or perspective) from one interviewee to another based on aspects of findings that required additional authentication and validation.

Table 4.1 Explicit Presentation of Broad and Specific Exploratory Questions

Building Blocks	Issues Raised/Missing Gaps	Primary Research Question	Broad Exploratory Question	Specific Exploratory Question
Time Factor	From 1934, 2003 right up to 2012, there has not been any indication of the time necessitated in transforming a nanotechnology prototype into a fully-fledged product and whether or not this time factor acts as an obstruction towards research and commercialization of nanotechnology - is a subject that has thus been relegated from research debate	Can time factor between research and commercialization of nanotechnology serve as an impediment towards the development of nanotechnology products and innovations?	• What is the estimated time between research and commercialization of nanotechnology? • What are the several engineering challenges that slow the progress/lengthen this time factor? • What are the possible engineering solutions performed to solve the dilemma? • Any risks and uncertainties that need to be addressed in pursuit of these solutions? • Why nano electronics? How long is the product development life cycle?	• Has the estimation of time factor between R&D and commercialization of nanotechnology magnetized conflicting opinions? • Are there any variations that exist in terms of field to field differentiations through their own activities and occurring conditions? • How would you describe the diversity of economic sectors with relation to that of time in terms of transitioning prototypes into fully fledged products for nanotechnology? • Is there any balance occurring between research activities and development activities, which are two pertinent components within a larger entity referred to as R&D? • What are the engineering challenges within the R&D arena that contribute to the escalating or unpredictable time factor during the transition?
Adaptability/ Compatibility	Intrusive vs non- intrusive nature of nanotechnology	Can the diversity of the new radical and disruptive technology allow it to acclimatize with existing systems or will it cause the previous and older technologies to become obsolete?	• The thing with nanotech innovations is that they usually comprise new materials that have very technical characteristics often never seen before. Do you consider this as an engineering challenge? • Do nanotechnology innovations need to strongly depend on complementary factors in order to succeed commercially? (Example: MRI technology depends on the availability of high field superconducting magnets, nuclear magnetic resonance spectroscopy and computer imaging) • Would you say that nanotechnology is more complex than biotechnology? • How diverse is this new radical and disruptive technology? • In what way can it acclimatize with existing systems? • Will it cause the previous and older technologies to become obsolete? • What factors will ensure that this radical and disruptive technology is going to be accepted commercially? And how lucrative will it be?	• Can nanotechnology innovations be developed into standalone applications without the need to acclimatize with other complementary innovations, applications and environments? • What are the technology factors that contribute to the adaptability and compatibility of nanotechnology innovations in coalescing with external environments and applications?
Initiatives	The absence of further contemplation to look into whether government initiatives can work out and solve the inadequacies in nanotechnology research and commercialization	Can government initiatives and incentives resolve the impediments faced, accelerate the research and commercialization of nanotechnology; and help spur firms to pursue nanotechnology as a commercial prospect?	• Do you think Malaysia is merely doing frontier research? • Meaning to say, are we merely going deeper into the knowledge of nanotechnology without bringing out any obvious applications?	• Are additional "lubricants" necessary for the development of nanotechnology due to the nature of its complexity compared to other technologies? • Have initiatives proved to be a positive catalyst in the transition and development of nanotechnology prototypes? • How successful have these initiatives been in

				demonstrating a positive correlation between initiatives and the development of worthy outputs? • Is our county ready to cross into the threshold of nanotechnology commercialization as yet?
Incentives			• There are only 4 nanotech firms in Malaysia. There are no barriers of entry/no monopoly that exist in the field of nanotechnology. Yet, why so few? • Out of these firms, none of them are manufacturing nano products, conducting nano R&D or have any ties with any universities. They are only sole distributors of nano products manufactured globally. What are the barriers that are hindering start-ups from conducting nanotechnology R&D, manufacturing and production? • Are companies today interested in transformational nano products or incremental nano products? • What are the barriers that are hindering large companies from conducting nanotechnology R&D? • Before funding comes in, a market must exist and research must move toward a product. Is there a market for nanotechnology products in Malaysia?	• Can incentives benefit larger companies to get involved in nanotechnology development? • Can incentives benefit SMEs to get involved in nanotechnology development considering its high investment and high financial risks? • Even if it is not nanotechnology specific, hundreds of millions of ringgit of government funding support our country, but we are still not equipped with one of the best research labs in the world? Why not? So many universities still complain of the lack of equipment required for nanotechnology? • How would you describe the nation /organization's commitment towards nanotechnology (Note: They invest in this technology on one year; then decide to cut investment the next year). Isn't this a disruptive environment? • Universities in Malaysia seem to have already recognized the existence of nanotechnology but our government does not seem to have recognized this technology yet. What would it take to bring this technology to their attention?
Multidisciplinary	Comprehensive vs non comprehensive: The hybrid	• What is the cost of setting up a sophisticated R&D lab for nanotechnology? • Can the level of knowledge absorption and awareness affect the interactivity concerning R&D and commercialization of nanotechnology? • To what extent can nanotechnology be diffused into the education curriculum considering the fact that the nanoscale concept has immense link to a combination of interdisciplinary or multidisciplinary subjects? • Which would a serve as a tool in	• What good will it do when students pursue a too broad an education and end up knowing little about many fields, but not enough in any one field to make a significant contribution? Note: Cross fertilization of specialist knowledge. Requirement of individuals of a hybrid nature who understands a variety of technical subject and facilitate the transfer of knowledge within the company (For instance: hybrid managers should have technical training and managerial training • What are the risks/uncertainties that come with pursuing the field of nanotechnology? How can we plan for the uncertainties that come along with nanotechnology? How do we deal with these challenges? • Hands on training vs. traditional classroom learning: Which would a serve as a quicker tool in producing human capital required for the commercialization of nanotechnology? Hands on training can be acquired in a shorter time span	• How would one address something as wide and comprehensive as nanotechnology? • Will the lack of proficiency in other scientific discipline leading to the study of nanotechnology prevent the learner who is proficient in a single area to pursue nanotechnology? • In order to contribute in the field of nanotechnology, are comprehensive learners mostly required as opposed to non comprehensive learners? • Will the proficiency in a single area of science create inflexibility in the movement towards expanding in the field of nanotechnology? • What if the university constructs a nanotechnology curriculum specifically for undergraduates whereby it will guide students from the perspectives of • Biology, Chemistry and Physics? Will that be good or bad? • What approach can be taken in the delivery of nanotechnology and how it should be addressed within the tertiaries of university education
Infrastructure	Infrastructural cost for setting up a state of the art R&D laboratory for nanotechnology			
Knowledge Absorption	Awareness and interactivity			
Skills transferability	The requirement and amalgamation of multiple skills and its transferability into the field of nanotechnology R&D and commercialization			
Education	Single area focus vs multiple areas of focus			
Human Capital/Workforce	The technical worker vs the knowledge worker			

		producing knowledgeable human capital required for the commercialization of nanotechnology? • How transferable are other diverse management and background skills and how quickly can they learn how to drive these new business models?	compared to traditional classroom learning which requires years of study. In other words, can the "capstone experience" be effective single-handedly given the fact that we need a solid number of nanotechnology workforce? • What is the cost of setting up an R&D department in nanotechnology? • What would be the cost of setting up a manufacturing plant for the production of nanotechnology products? Since those required in a sophisticated lab is not the same as those required in a rough and tumble such as a manufacturing plant. • When it comes to human capital, in many companies, senior management is being recruited from leaders in other industries, often from IT and other electronic businesses. While some of these people often come from outstanding track records, however when it comes to this new field of nanotechnology, how transferable are their skills and how quickly can they learn how to drive these new business models? • They say one of the challenges is to manufacture these materials in large volumes with consistent quality at a reasonable cost. Why? • What are the factors that contribute to the cost of setting up a manufacturing plant for the production of nanotechnology products? • Since those required in a sophisticated lab is not the same as those required in a rough and tumble such as a manufacturing plant?	(undergraduate, Masters, PhD)? • Are there any prospects for nanotechnology to exist as a standalone discipline? • Is the hybrid expertise of the field of nanotechnology considered to be comprehensive or non comprehensive learners? • What are the problems/challenges of conglomerating the various specialists in the sciences of nanotechnology? • What are the problems/challenges that would lead to the difficulties in constructing a standalone nanotechnology program? • In the field of nanotechnology, which requires high levels of training: The technical worker or the knowledge worker? • What about the expertise of using microscopes and the expertise of maintaining microscopes, which are widely used in the field of nanotechnology: Whose expertise is required the most: The technical worker or the knowledge worker? • Is there a standard and well defined cost for instituting a laboratory for conducting nanotechnology experimentations? • In the field of nanotechnology experimentations, can the acquirement of high cost equipment be compromised in favor of low cost equipment? • Are high cost equipment a matter of maximum utilization in the field of nanotechnology? • What factors are nanotechnology experimentation equipment dependent on? • In the area of nanotechnology management: Which is more crucial? Is it the understanding of technology expertise or the impact of technology towards its target consumer market? • Would be a matter of great importance to incorporate the management of technology into the nanotechnology curriculum?
Research Opportunities	Nanotechnology opportunities within the non-science	• To what extent can non – research colleges and universities take advantage of these opportunities considering the fact that nanotechnology still remains a field that is heavily research based?	• Can nanotechnology be incorporated into the undergraduate curriculum particularly in Management, Information Technology, Social Sciences degrees and also in the MBA curriculum in a comprehensive way?	• How can nanotechnology be immersed in a comprehensive way into non-research colleges without the use of high tech laboratory facilities?

R&D Policy	The formation of R&D policy for nanotechnology	• Will there be a need to call for unification of R&D policies and procedures concerning the multispectral nature of nanotechnology?	• Given the fact that nanotechnology is being developed and applied in many different fields or sectors of the economy, how will the government synchronize the principles and standards derived from each sector? And make it one single sector?	How will the governing body create and put into effect policies regarding its R&D? (In terms of legal mechanisms such as tax codes, patent law, and anti-trust regulations)
Sustainability Partnerships Patents Publications	The right thermometer of standing The distinct priorities of academia and industry and how it affects the R&D and commercialization of nanotechnology	• To what extent have strategic partnerships ensured the long-term sustainability in the field of nanotechnology? • Does the phenomenon whereby publishing and patenting move away in two (2) separate directions in the form of two (2) separate activities hinder the R&D and commercialization of nanotechnology?	• How can strategic partnerships ensure long term sustainability in the field of nanotechnology? • Do you think more universities professors should become affiliated with the companies that conduct nanotechnology R&D to make strategic partnerships to be successful? • How will the universities' management know if the strategic partnership is in fact actually working? • What will the thermometer of measure be? • To what extent are strategic partnerships doable and how long will it last? • Do the academic need to publish and the indust need to patent hinder the commercializat process? • Do you think there should be a separation betw the two?	• Are both academia and industry moving in two different directions? • What are the challenges faced by industry in partnerships in terms of working with academia? • What are the challenges faced by academia in partnerships in terms of working with industry? • What would be the possibilities of occurrences if the university were to work alone? • What are the expected intangible benefits that transpire from constructive partnerships? • Does a partnership directly develop the expertise of the academician? • Are large companies making use of university infrastructure for nanotechnology R&D? • Are start-ups making use of university infrastructure for nanotechnology R&D (or vice versa)? • What potential benefits do these companies expect to gain if it invested in those R&D projects? • Who gets the first right to apply for a patent? The university or the partner company • Who bears all costs incurred by the patent applications • Are you research results available for further research and education purposes? • Where does your funding come from? • Do you fund PhD students and postdocs? E.g. provide grants and training • In many countries/research institutes, many inventions (esp. nano inventions) are never patented, either because of the time and effort required to acquire a patent or because they do not want to publicly disclose the operation of their new product or process. How is it in your company?

4.7 The Qualitative Data Gathering Process: Formality of Setting

A total of eleven (11) in - depth interviews were conducted with ten (10) participants; meaning one interview was conducted with each participant. These ten (10) participants consisted of professors, researchers and also directors/heads from universities, research institutes and also ministries within Malaysia. Four (4) out of ten (10) participants were chosen for their fine blend of both industry and academia put together; whereas seven (7) out of ten (10) participants were purely from academia. Each participant was contacted via email explaining to them the purpose of the nanotechnology study. Each participant was interviewed one to one separately at his or her own premises (department/institution/faculty). Focus groups could not be carried out since these participants were not able to schedule themselves to the same time/date and venue. Therefore, one to one interviews which proved to be the best option were carried out between the mid of May 2012 and mid of December 2013. The time taken for each interview averaged between 70 and 90 minutes. Depending on the thesis area under discussion, economic sector, organization and area of expertise of the interviewees, technical and non – technical form of questions were meticulously planned and outlined prior the interview. Each of these participants had expertise from various fields of sciences such as nano materials, nano advanced materials, micro engineering, nano electronics, catalysis, nanotechnology and combinatorial chemistry, mechanical engineering and nano structured materials.

Questions that participants were asked to articulate upon were based on the subject of nanotechnology R&D and commercialization. This qualitative method was conducted using an "open ended" approach whereby the questions were not worded in exactly the same way with each participant. The participants were open to respond in their own words that which paved way to a more complex and multifarious form of responses that went beyond than a mere "yes" or "no" (fixed responses). Meaning to say, these respondents were given ample opportunity to give their convoluted and detailed views on the subject in question. As a researcher, I had the opportunity to respond and probe immediately to what the participants had to say by crafting subsequent questions to information the participants had provided. Interview questions were never given to the participants in advance. In other words, the interviews were conducted using an impromptu technique in order to evoke spontaneous and unanticipated results rather than rehearsed responses. Interim analysis (*ongoing and iterative*) was carried out until the subject matter had been greatly understood and sufficient data had been gathered to provide evidence to satisfy the research questions. Interview data was recorded with the permission granted by each participant prior to the interview and each recording was transcribed into computer files. Considerable amount of time was taken to transcribe the recordings of each participant in order to capture the essence of their insights in their own words. Each of the participants was also assured via email that there were no risks associated with participating with the research study.

Prior to the interviews, a rigorous and analytical literature review was conducted in the field of nanotechnology innovations, product and process innovations and existing policy implications of nanotechnology. Literature review was continuously performed throughout the PhD thesis study to systematically keep abreast of new developments in the field of nanotechnology to avoid writing the literature review more than once. During the examination of literature, missing gaps were deracinated and were converted into 14 research questions. Their answers have been dealt with under the findings section of this paper. Each participant was asked an average of between 20 and 25 interview questions (to justify the 14 research questions) depending on the length of their responses and time available. All interview transcripts generated for the purpose of this study were thoroughly analysed and coded in the style of a grounded theory approach to data analysis. All data under the findings section of this paper have been accounted for. In signifying the reliability and validity of this research, the method of triangulation was used to check the conclusions from one data source to another and also to unearth the complexity and of finding different views. The contradictions and differences within the data collected went through further analysis and investigation until a clear cumulative effect of the findings could be established. The data, analysis and evaluations were finally transferred into a PhD Dissertation write-up. Figure 4.6 shows an illustrative overview of how the research methodology was carried out for the purpose of this thesis study. A total of ten (10) middle – level/high level personnel from organizations were communicated multiple times from 2012 – 2014 regarding statistical information pertaining to their organizations and latest developments in terms of grants and funding for nanotechnology in Malaysia.

4.8 Sampling Technique: Purposive Sampling

4.8.1 Rationale for Selecting Purposive Sampling

This form of sampling was made use of in this study due to its flexibility in terms of selecting respondents according to a particular research purpose or research question. Sample size was not fixed prior to data collection and strongly depended on the time and resources available. It also strongly depended on the thesis objectives. According to Kelly and Richard (2000), purposive sampling enhances understanding of selected individuals and provides greater insight into the research question.

4.8.2 Sampling Criterion

In this study, a total of ten (10) respondents were carefully selected to investigate the thesis objectives and thoroughly analyse the research questions. These respondents were identified based on a selected criterion set by the researcher. Sample was determined based on the following criterion:

- Area of specialization
- Position held in the organization/CoE to demonstrate the authority of given information
- Consisting the fine blend of both industry and academia or purely from academia
- The level of active participation in the area of nanotechnology
- The availability of each respondent to provide quality information and responses through interview sessions within the given timeframe to conduct this thesis study

This sampling technique did not directly employ the technique of snow balling whereby the respondent directs the researcher to another potential participant. This technique was not employed because the snow balling technique clutches on to the possibility of conglomerating and relying on the needs and social network of the respondent alone instead of the needs specific to the study. Without relying on the social circle or contacts of the respondent single-handedly, the phenomena harnesses (connects and controls) the study to a specific criterion set by the researcher alone. Figure 4.2 describes the purposive sampling methodology

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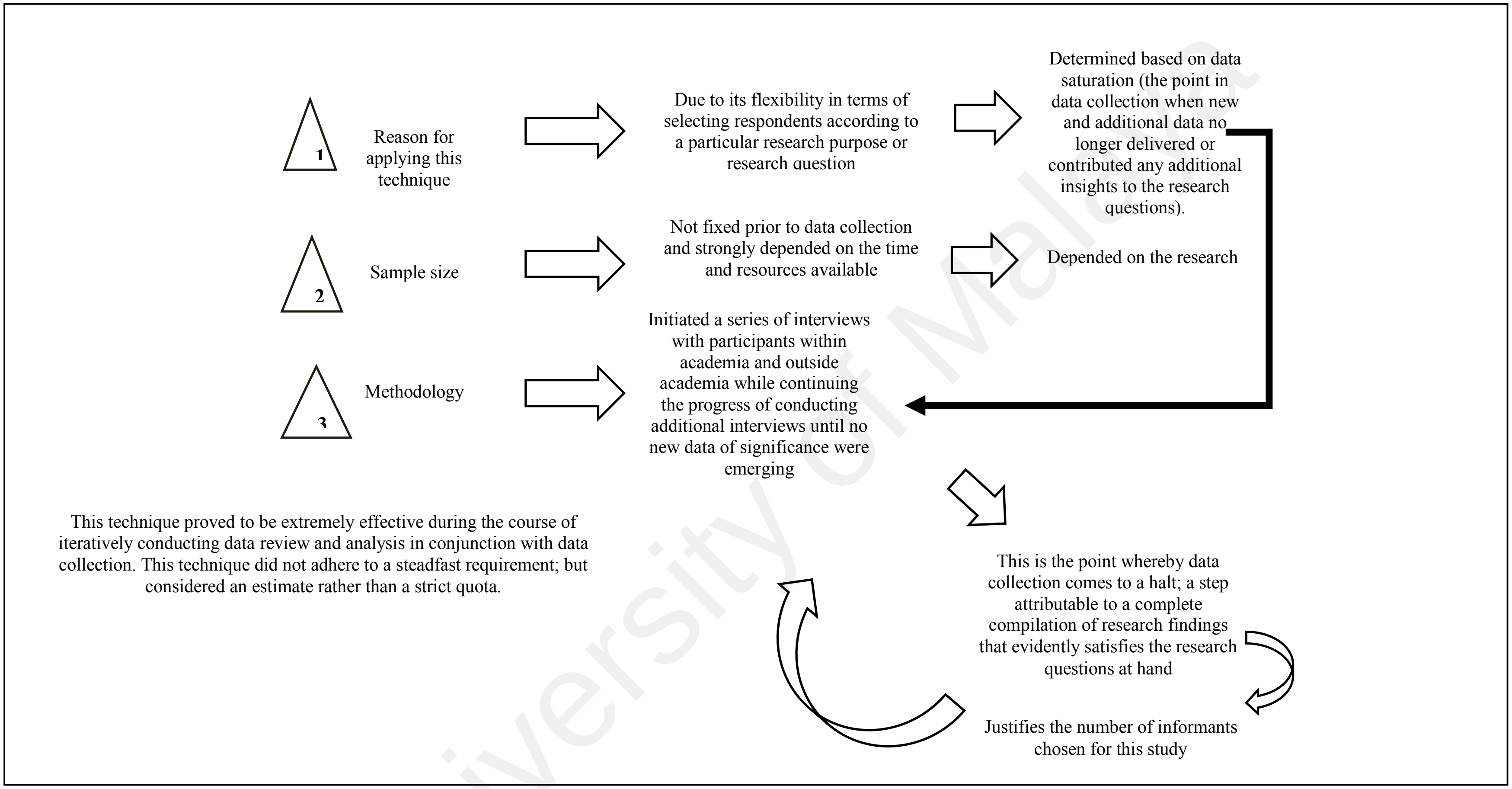
Figure 4.2 Description of the Purposive Sampling Methodology



Source: Author's Design

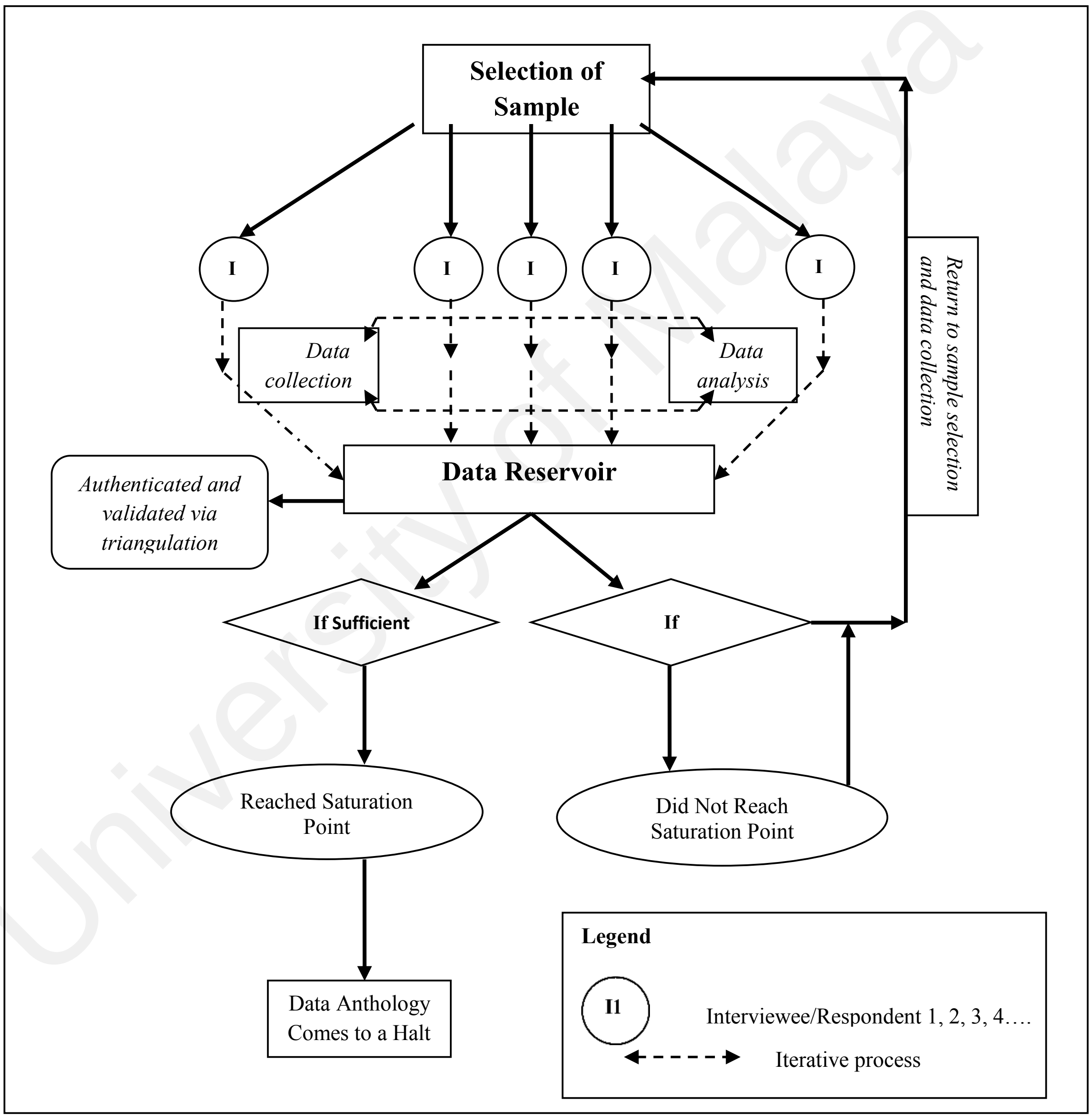
4.8.3 Saturation

This purposive data sampling technique was determined on the basis of theoretical saturation (the point in data collection when new and additional data no longer delivered or contributed any additional insights to the research questions). This is the point whereby data collection comes to a halt; a step attributable to a complete compilation of research findings that evidently satisfies the research questions at hand. This technique proved to be extremely effective during the course of iteratively conducting data review and analysis in conjunction with data collection. This technique did not adhere to a steadfast requirement; however, it considered an estimate rather than a strict quota.

4.8.4 Validation Technique: Triangulation Method

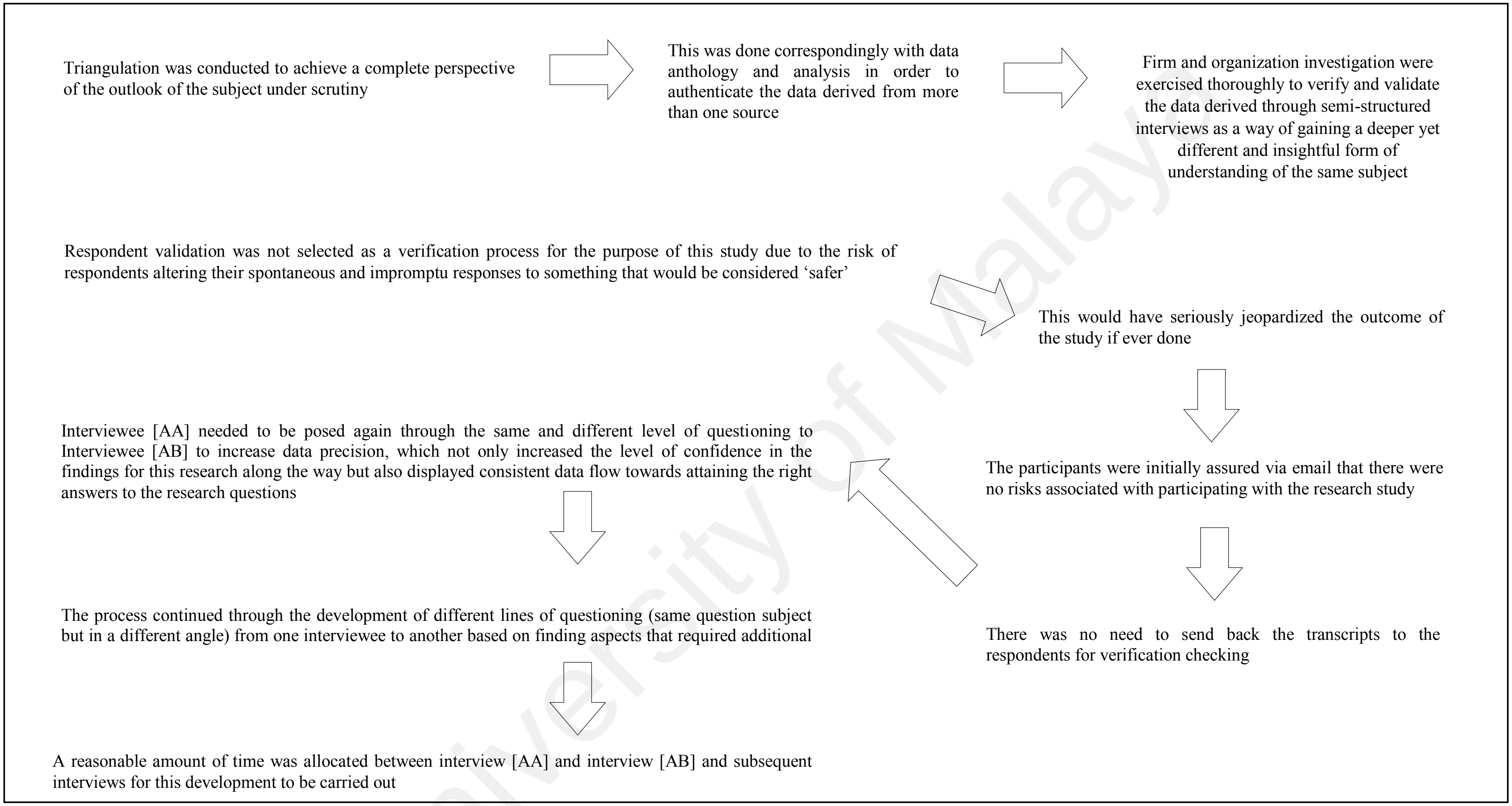
The primary purpose of conducting triangulation is to achieve a complete perspective of the outlook of the subject under scrutiny. This was done correspondingly with data anthology and analysis in order to authenticate the data derived from more than one source. Firm and organization investigation was exercised thoroughly to verify and validate the data derived through semi-structured interviews as a way of gaining a deeper yet different and insightful form of understanding of the same subject. Respondent validation was not selected as a verification process for the purpose of this study due to the risk of respondents altering their spontaneous and impromptu responses to something that is considered more 'safe'. This would have seriously jeopardized the outcome of the study if ever done. The participants were initially assured via email that there were no risks associated with participating with the research study. Therefore, there was no need to send back the transcripts to the respondents for verification checking. Verification was solitarily conducted by way of triangulation by the researcher alone. Furthermore, the key strength of triangulation is to unearth the complexity hidden between different insights. The contradictions and differences within the data anthology prompted for further analysis until a clear sense of the subject could be envisioned. Figure 4.3 illustrates the process flow of purpose sampling and triangulation used in this study and Figure 4.4 illustrates triangulation in more detail.

Figure 4.3 The Process Flow of Purposive Sampling and Triangulation



Source: Author's Design

Figure 4.4 Triangulation



Source: Author's Design

4.8.5 Confidentiality of Sample Distribution

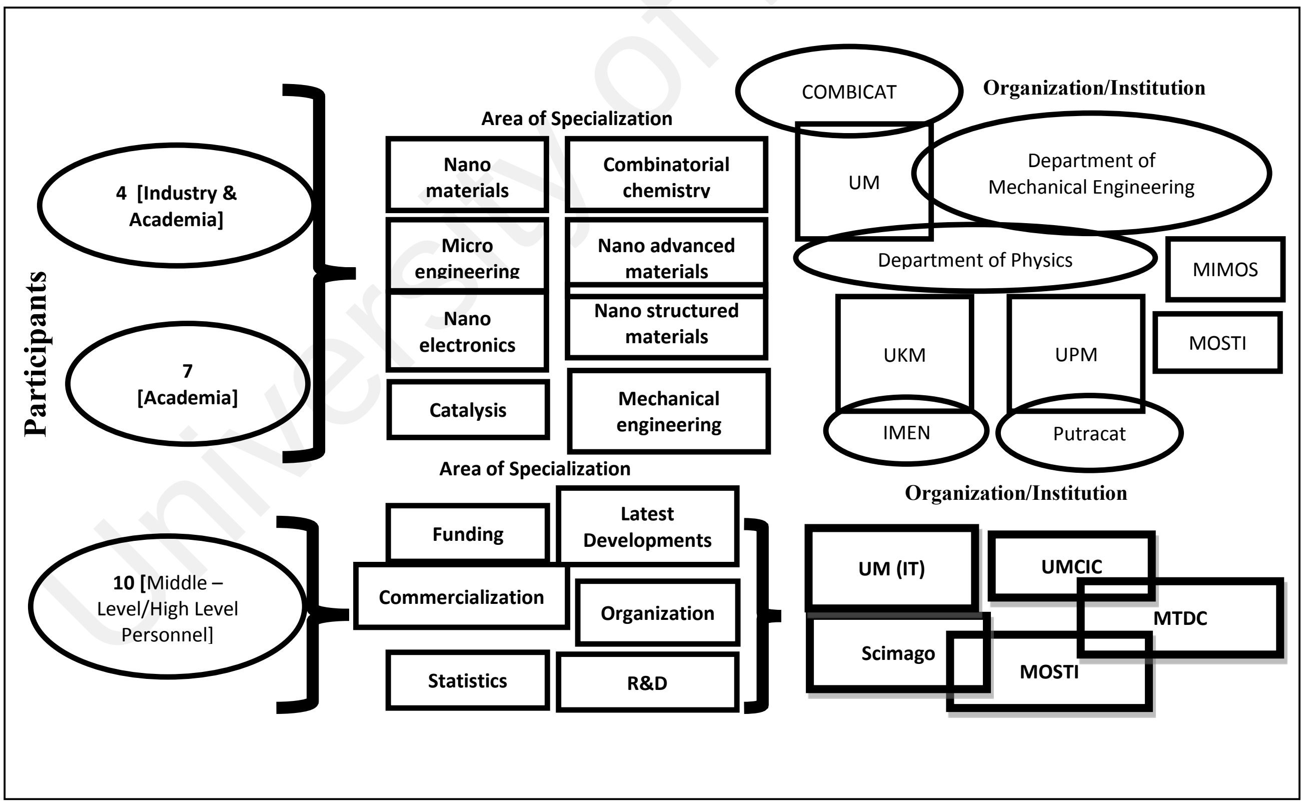
Table 4.2 is an alphabetical code representation of the ten (10) respondents participated in this research used to conceal their actual identities and Figure 4.5 illustrates the distribution of sample.

Table 4.2 Author's Alphabetical Code Representation of Respondents

INTV	CODE[44]	AREA	INTV	CODE	AREA
1	AA	A/I	6	AQ	A
2	AB	A	7	AG	A/I
3	AC	A/I	8	AX	A
4	AD	A	9	AI	A/I
5	AE	A	10	AU	A

Legend: INTV: INTERVIEWEE / A: ACADEMIA / A/I: ACADEMIA/INDUSTRY

Figure 4.5 Sample Distribution



Source: Author's Design

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44 Codes are used to represent the respondents' quotations within the findings and analysis section of this paper to conceal the actual name, location, and university or industry affiliation in order to protect their identities. Four (4) out of ten (10) participants were chosen for their fine blend of both industry and academia put together; whereas six (6) out of ten (10) participants were purely from academia.

4.8.6 Sample of Interviewees, Designation and Institutions

These interviews were conducted between the mid of May 2012 and mid December 2014. Table 4.3 displays the designation of study respondents and their respective institutions. Table 4.4 displays the middle – level/high level personnel from organizations were communicated multiple times with regarding statistical information pertaining their organizations and latest developments in terms of grants and funding for nanotechnology in Malaysia from 2012 – 2014.

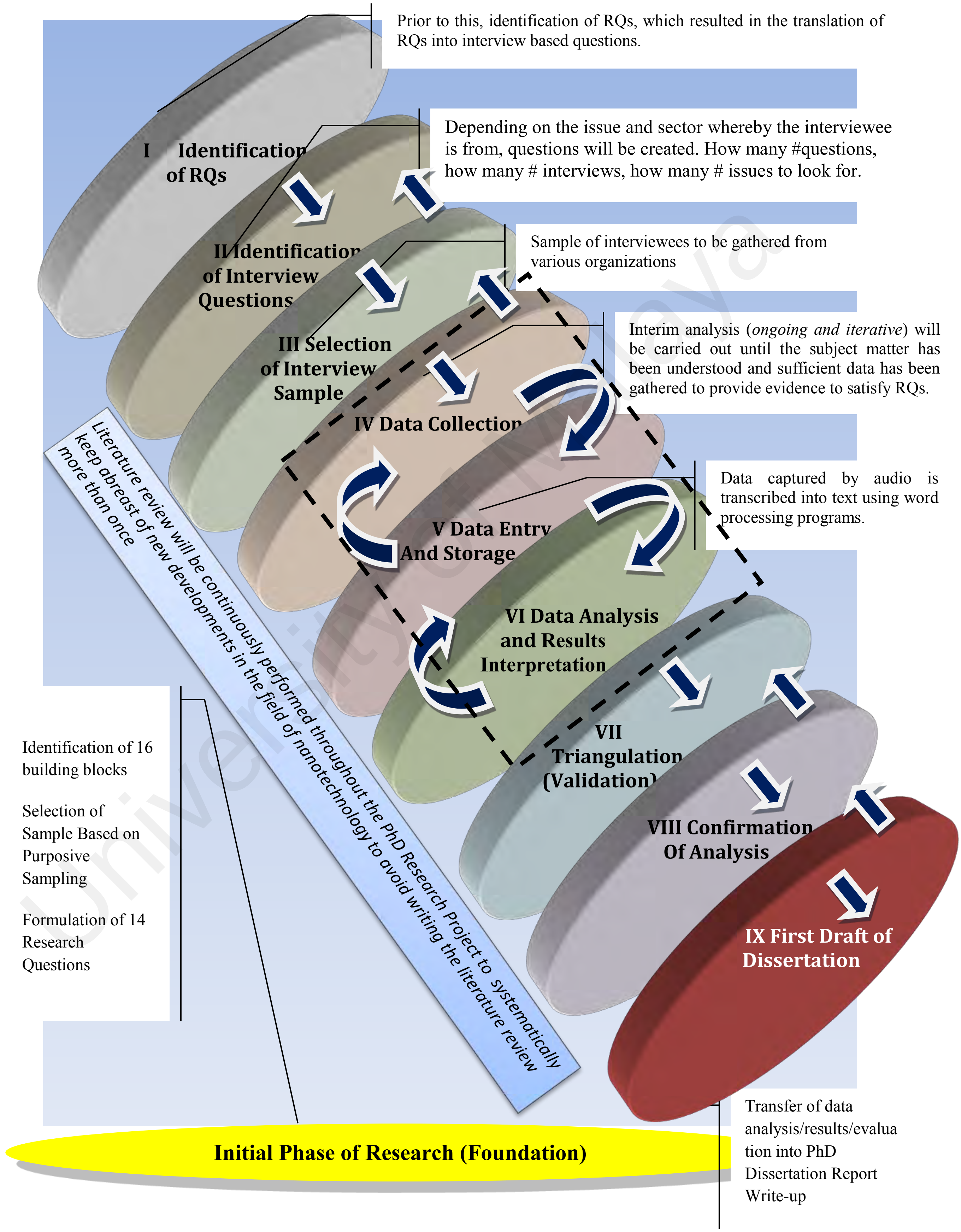
Table 4.3 List of Respondents and Institutions Interviewed

Designation of Study Respondents	Department /Institution/University
Professor	Department of Mechanical Engineering, UM
Professor	COMBICAT: Department of Chemistry, UM
Lecturer/Researcher	Department of Mechanical Engineering, UM
Lecturer/Researcher	Department Physics, UM
Professor	IMEN, UKM
Director	MIMOS, Bukit Jalil
Researcher	MIMOS, Bukit Jalil
Professor/Director	Ministry of Science, Technology and Innovation (MOSTI) Putrajaya
Professor	Department of Mechanical Engineering, UM
Professor	CoE PutraCat, Faculty of Science, UPM

Table 4.4 List of Middle-Level and High-Level Personnel Interviewed

Middle – Level/High Level Personnel	Department /Institution/University
Research Officer	National nanotechnology Directorate (NND), MOSTI
Research Officer	Science Fund Section, MOSTI
Research Officer	IT Centre , University of Malaya
Director	Technology Transfer and Commercialization Division, MTDC
Research Officer	Malaysia Technology Development Corporation (MTDC)
Research Officer	SRG Scimago Research Group
Research Officer	National nanotechnology Directorate (NND), MOSTI
Research Officer	UMCIC
Research Officer	National nanotechnology Directorate (NND), MOSTI
Head	Grant Evaluation, MTDC

Figure 4.6 Air Inflator Pump - Reciprocation Model: Author's Research Design



4.9 Summary

This chapter has explained the design of the conceptual framework for this thesis through the formation of building blocks used as individual units of construction composed to formulate a larger subject entity that may interoperate with interdependent units of construction. Building blocks have been clearly labelled and conceptual framework has been diagrammatically illustrated. This chapter has also provided an explicit presentation of exploratory questions designed for this study and the author's (researcher's) very own research design model. Sampling method via purposive sampling and triangulation have been explained in terms of reason, sampling size and methodology. Limitations that constrained the researcher and that which formed solid ground in choosing a qualitative methodology instead of a quantitative approach in the process of generating findings for this study have also been explained. This chapter paves way to the next following chapter, which is Chapter 5: Findings.

CHAPTER 5: Findings

5.1 Introduction

This chapter investigates the barriers that limit the innovative transition from nanotechnology R&D to commercialization through the building blocks constructed within the conceptual framework designed for this study.

5.2 Interpretation of Results

The main findings from this study are within the three (3) dimensions and are presented in the following 14 themes: time factor, adaptability/Compatibility, initiatives, incentives, patents, infrastructure, multidisciplinary, publication, knowledge absorption, skills transferability, sustainability, partnerships, R&D policy, education and human capital.

5.2.1 Time factor between research and commercialization of nanotechnology

The estimation of time between research development and commercialization has always magnetized conflicting opinions due to the uncertainty and improbability that occur between the transition processes that stems directly from the level of prototype into the level of a fully-fledged product, which is ready to market. If one was to look at translating an R&D prototype into a product ready to market, it will vary from field to field and one cannot generalize. This is an indication that the diversity of economic sectors contributes in parallel to the length of time required to complete the transition process and does not constitute to a standard time frame. If the medical field is taken for instance; given that there is the requirement of clinical health testing and acceptance, the field will be looking at approximately 10 – 15 years. If there are genetically modified crops or pharmaceutical products that need to be released into the market, it has to first go through FDA. That alone will take a minimum 1 year just to make sure the testing is done properly. Stirring along is the robustness of the technology and its biocompatibility, which are also set under check. What is being signified here is that in the case of the medical or biological or pharmaceutical, there are factors such as the standard clinical and post development technical procedures prior to market release that adds on to the time in totality. The addition time taken here does not equate similarly to the time taken in other areas of the industry. For instance in the case of biotech, oil and gas, then it is at a range of a shorter time factor. The success stories are in the range of 7 years and 7 years is considered rather fast. And if we were to move towards a field that requires less complexity, it may take 3 years to come out with an alpha type prototype – a prototype that has the potential to be commercialized, but not ready to be commercialized, even though venture capitalist will prefer it to be between 2 -3 years.

In research, what needs to be seen is the proof of concept (POC) - when researchers build something first to show whether the concept is correct. And once the concept is proven and established to be correct, the process to make the product is begun. Slowly, the design aspect comes into the picture. This is development. For example to make a cup: The research part will be to devise and formulate the material that will stand a certain temperature, but to construct and craft the cup to look a certain way, that is not the job of a researcher but the job of a designer. Therefore, what is being signified here is that the absorption of an exacting time concentration is not balanced between R&D. There are cases where research takes longer than development itself or vice versa. There are times where the meticulous design of a certain product, which can exert a pull on the consumer market can take longer than the time taken for proof of concept (POC). Still these time evaluations and inferences remain to be irresolute and unconvincing because one researcher provides a very pragmatic view to state that,

> ***AG:*** *5 years is comfortable. 3 years is really stretching. There should all kind of assistance and initiatives taken to make it to reach fulfilment in 3 years, inclusive of market release. But 5 years is reasonable for majority of products.*
>
> ***AE:*** *It will take a minimum 7 – 10 years from basic research.*

In the case of nanotechnology, it is of no exception. If nanotechnology is going to get into the medicinal, that means oral, the medical scientists need to follow the identical suit. It is not to say that in the case of nano, one has to plus another year or another two years. It doesn't operate through that kind of mechanism. Nevertheless, in the case of nano, safety plays an important role in determining whether or not the full conversion from prototype into product is ready for market release. But another element that can contribute to this time factor is the methodology or synthetic technique that is applied to the process. For instance it is the methodology of producing the morphological surface of a nanoparticle. Nanoparticles come in diverse shapes. It could be spherical, it could be cubes. Therefore, the challenge is to produce it in the shape of spherical, so that it is all uniform. This connotes that the methodology or synthetic technique is very pertinent in the field of nanotechnology because different shapes gives out different characteristics.

> ***AQ:*** *The nanoparticle and the nanotube come in two different shapes. The nanoparticle for instance consists of mechanical, optical, and electrical characteristics, but alternatively if we produce carbon nanotubes, its*

electrical characteristics are much higher than the electrical characteristic of a nanoparticle.

Therefore this finding explicates that shapes play a crucial role in the field of nanotechnology, but the precision and intricacies involved in constructing a consistent and homogeneous shape, such as the spherical can contribute to the increased time factor. There are also engineering challenges that can augment the time factor between research and commercialization.

AA: *For example, in nano electronics, the difficulties endured when it comes to the nanoscale is getting the reproducibility in characteristics in the electronic device. To make one transistor to repeat with another transistor – in the sense to make it uniform, that is a technological barrier. This is because the physics at that size - is hard to get it very regular.*

AB: *When you develop the technology, normally you come out with 2 – 3 prototypes, but when you go commercial, it has to be 1 million – 20 million. You need to have that volume. Production of large volumes is a challenge especially at reasonable cost and high quality. It is easier to make them at small scale but to make at a large scale would be difficult in terms of the reproducibility.*

AX: *When you do a small number, you can control the parameter. You can make sure the performance is at a certain temperature; whereby you can* *"twig" (optimize) your recipe so that it will meet the requirements. But if you do one (1) million, you don't have all the time in the world to make sure that every single device is "twigged" (optimized). It is the procedure that makes nanotechnology complex.*

What is being emphasized here is that there is a lot more physics that goes into it whereby researchers even experience certain processes happening outside the ordinary.

AU: *Getting the sanction and endorsement is a whole new ball game altogether. No matter what happens, the nano product needs to be certified as safe and out of harm's way for consumer use.*

AI: *Nobody wants it turn out to be the asbestos scare. Some people feel that things can get out of control. Sometimes the product may be ready for the market; but the market acceptance will not subsist because of the fear of the unknown.*

Nevertheless, these findings does not comprehensively connote that the safety issue is the foremost cause of a lengthened time factor. However, it stresses that the product readiness that influence market penetration, market acceptance and eventually market replacement need to be fully fortified in all facets prior release in order to thwart the product from being declared unfit to suit customer needs. Therefore, these findings also indicate that: what use will all the efforts (in terms of time) devoted to the R&D development and commercialization activities of the product, if the product ends up a failure in the market (sits in the shelf) all because of the public's pessimistic perception of nano.

> ***AD:*** *There should be another group of people who needs to work closely on the awareness and the safety and health issues of potential nano products.*

When it comes to issues like Intellectual Property (IPs), the superfluous number of IPs that are existing today does not however equate to commercial success.

> ***AE:*** *There are lots of it. But in a range of 100 IPs, only 5% – 10% gets into commercial production. It's very much dependent on the market and the cost of making the product.*

Another element that needs to be considered is what the term R&D in point of verity means to people in general.

> ***AG:*** *The minute people think R&D, they assume that something out of this world has been discovered and is ready to go straight for commercialization. That is a wrong conclusion.*

This finding indicates that R&D is not a simple endeavour as what people perceive it to be. The truth of the reality is R&D is not a single stage process. It is segmented into at least 3 different stages ranging from basic research to supply; right into development. Further segregation will involve the stages of study and investigation that comes prior to basic research. So what is observed from this is that there are two (2) extremes: One is preliminary study and other extreme is solution development.

> ***AQ:*** *But at the end of the day, what the consumer buys is not the R&D. They don't buy the knowledge or the findings that went into producing the product. The consumer is ignorant of those efforts. They only want to buy the solution. In the sense: What can the product offer them?*

Thus, in the case of nanotechnology, the consumer is interested to know what kind of benefits is offered to them in comparison to a non-nanotechnology product. Is it lighter, faster, more durable, tastier, cheaper, safer, and multi-functional? Hence, what is being implied here is that the time factor between research and development needs to be closely looked into so that it is in line and parallel with and guided by the market needs that goes into devising the nanotechnology product.

> ***AA:*** *We don't see change after 5 – 6 years. We see change every year.*

Therefore, a longer time frame will be detrimental from this aspect.

> ***AC:*** *It is also depending on which segment, which product or which field of focus. For example, if you are talking about consumer electronics such as the cell phone, it is common to expect new R&D to complete within 7 – 18 months. The lifetime value of a customer is predicted to be two (2) years.*

After two (2) years, it is unlikely anyone can trade their cell phones anymore.

In this aspect, nanotechnology is no different. This finding also indicates that market expectations and needs change rapidly with time and thus no time should go dissipated in efforts that do not directly contribute to the transformation from a nanotechnology prototype into a fully-fledged product. Since redundant time will only function as a barrier (lengthen the time factor) to the R&D and commercialization of nanotechnology products, long range planning is essential preceding R&D. Therefore, what can be concluded is that the clinical procedures, the complexity of the field and process, the methodology and technique, the sanctions, the level of product readiness, the market needs and the quality of basic research ultimately contributes to the time factor between research and commercialization of nanotechnology. It can also be construed that the lack of these elements are impeding the R&D and commercialization of nanotechnology. Nonetheless, in the case of Malaysia, the current development of nanotechnology's environmental setting do not share an identical footing compared to other countries. It can be professed that Malaysia's developments in the area of nanotechnology is not as significant and momentous as compared to other countries which are spearheading the global nano race.

5.2.2 Impact of initiatives towards universities research and commercialization for nanotechnology

Initiatives in this sense are associated to "support and facilities". Support generally comes in the form of funding and facilities come in the form of physical equipment, laboratories and workspace.

> ***AG:*** *These are considered to be 'lubricants' from the government. One is technology and the other is infrastructure. Another one is people's mind-set, human capital and skill group.*

These are the recognized and acknowledged elements known to mankind to coerce and to controllably oscillate any kind of technology whether it is nanotechnology or biotechnology.

> ***AQ:*** *Nanotechnology is more complex than biotechnology…….you need a lot of imagination to visualize its movement in terms of atoms and molecules……..and the ability to manipulate the nano size.*

However, this particular finding does not imply that additional 'lubricants' is necessitated due to the nature of its complexity.

> ***AB:*** *What is the cohort required is the number (%) of scientists or the technopreneurs' or the entrepreneurs' to translate and push the nanotech prototype into product and later into market as opposed to biotech.*

This finding on the other hand implies that nanotechnology will require additional 'lubricants' in terms of expertise and know – how as opposed to biotechnology. Nevertheless, whether or not these initiatives can serve as a catalyst is somewhat to be monitored closely.

AG: *It's not something that we can control. For example if we want to measure the lifetime of radios – the conventional method is to wait. Buy 10 radios, leave it on and see how long it will last. Another way is accelerated testing. Place the radio in the chamber or expose it to the rain – meaning we place more stress to the device and see how long it will last. Then conduct a 1 month simulation in the lab. Simulation will predict 10 years.*

In the circumstances wherein reducing the time factor between research and commercialization is concerned, this finding indirectly proposes a conventional waiting method whereby we invest and wait for the fruits of our labor (which may take 10 – 15 years) or we can augment the number of hours and number of specific expertise (add the level of stress) in order to accelerate the transformation process. As a result, the process becomes more intensified. In the case of Malaysia, MOSTI initially initiated two (2) programs called the Techno Fund and Science Fund and recently another two (2) known as the Inno Fund and Nano Fund. The Techno Fund was widely used to generate and produce prototypes that can be pushed to market. The amount of Techno Fund is limitless (unlimited). Therefore, a great number (number not specified) who receives the Techno Fund grant have with them a prototype that has the potential to be patented and pushed for commercial market.

AI: *Prior to all this, a market did exist. But the period taken from converting an archetype into a complete product was protracted. It was only subsequent to the funding initiative, it has been observed that the process* *could be accelerated because it served as an inducement to researchers to focus on producing research outputs that can be commercialized.*

This finding nevertheless does demonstrate that there is a positive correlation between initiatives induced and period taken for the transformation process if ever done successfully but there are no statistics to verify how successful these initiatives have been in the last four (4) years since its establishment. Nevertheless, few experts believe that in contrary to the existence of initiatives set up to catalyse nanotechnology, the question of whether or not our country is ready to cross the threshold of nanotechnology commercialization is highly debatable.

AI: *The focus of nano research should still be confined within the realms of basic research (fundamental). We should not be so constrained to move towards commercialization yet because there is still lack of knowledge in the basic problems underlying nanotechnology that needs to be pre-solved before we can shift our focus into commercialization.*

This finding does not suggest that researchers have not progressed towards applied research. They have. But, as a researcher states to say that,

AC: *If scientists experience certain discrepancies during applied research, then they have no alternative but to move back to basic research.*

Another point that needs to be considered is while no entity is contradicting the verity that the funding and support from high impact research do exist, it remains a query as to why not many transformations from prototype to product have not yet taken effect in our country.

> ***AX:*** *When you apply for a lot of these grants, whether it's the Techno Fund or the Science Fund, majority of the time, they don't give money for equipment. They do provide endowments that serve as disbursements to Research Assistants, MSc and PhD students which include travelling expenses. Another type is the endowments that are left to the institutions to plan for themselves. But if the institutions are not well planned, there will be a tendency for a short circuit.*

Therefore, this finding signifies that the unavailability of the equipment for nanotechnology has nothing to do with the matter of funding. The funding already exists.

> ***AA:*** *The infrastructure is not integrated and looped in a comprehensive way for all parties to benefit*.

In contrary to these findings, a researcher states,

> ***AB:*** *From what is observed, before high impact research, there was likelihood to obtain high amounts of funding (not specified). That is no more to be seen now. Currently the endowments are shrinking from phase to*

phase. It's difficult to get even 2 million in funding now for projects as complex as nanotechnology.

As a result, there is an existing void. This could be seen as a sign of policy change in universities whereby as a researcher states,

> ***AX:*** *Funding has never been periodically monitored. However, there have been attempts to put up a process to make sure we really monitor according to work plan, the deliverables; not only how we spend the money but the outputs will also be monitored.*

Funding will be disbursed according to periodical research outputs; no output equals to no funding. This could possibly explain the shrinking effect; an attempt that could stimulate the rise of quality expertise and fuel world class research in nanotechnology.

5.2.3 Government incentives in spurring involvement into nanotechnology

There have been suggestions made in the past for governments to offer incentives that can impel the enticement of companies to get involved in nanotechnology. However, in retrospect, these incentives may serve as an effective method to spur SMEs such as tax reductions, loans and grants but in the case of large companies, it will prove to be unsuccessful.

> ***AE:*** *No government stimulant can entice a rich company. If they believe they want to come out with their own IP, they have their own funds. The industry needs to recognize for themselves what their priority is. If their*

priority is towards oil recovery and improvement, it is their onus to make sure that there is continuous flow of oil.

This finding brings out the notion that each company has got their own policy and it is in their policy to recognize the importance of nanotechnology and set forth their priorities if the need arises. Instead of government giving out grants; if the large company is interested in venturing deeper into this technology, then the possible option would be to entice the large company to provide grants to universities to conduct research in nanotechnology. Government incentives nevertheless can assist SMEs tremendously and significantly.

Kasthoory (2007) provides evidence through a series of case studies that the incentives given out to SMEs such as tax reductions, loans and grants positively correlates to the success rate of SMEs in terms of purchase of equipment, workspace, R&D laboratories and these incentives have significantly helped in prolonging the survival rate of SMEs. In the case of Malaysia, the number of SMEs involved in nanotechnology is scarcely. Several universities such as University Science Malaysia utilize small firms to market their products. But this company is an agency under USM. However, presently (as of Nov 2012), there have been few listed firms in Malaysia who are involved in nanotechnology. Due to the unavailability of proper coding systems to classify firms according to specific nanotechnology related activity and to make known to universities as to whether or not they are purely nanotechnology based disables the ability to properly target the right firms to establish partnerships. Information gathered is as follows:

Table 5.1 Nanotechnology Related Companies in Malaysia

Companies	Level of Involvement of Nanotechnology
*CREST GROUP (CREST NANOSOLUTIONS SDN BHD)	Do not manufacture any type of nano products; only the sole distributor/supplier of microscopy equipment manufactured in United Kingdom, Japan, Holland, US to universities who conduct nano R&D. Provides solutions to nano users. Do not conduct nano R&D. No collaborations with universities in terms of R&D.
ARCH FLASH CORP SDN BHD	Only manufactures one (1) type of nano product. But the registered address is occupied by another company. No product brochure and no registered address to indicate product and company existence or proof of any collaboration with partner universities.
NANOAIRE SOLUTIONS	They do not manufacture nano products but was a sole distributor of a nano product (before). They received the CRDF grant from MOSTI a few years ago. But the company no longer exists. Their website/telephone number also does not operate anymore. No company website.
*DKSH TECHNOLOGY	Does not manufacture nano products; the sole distributor for two (2) nano products manufactured in UK. Does not conduct R&D or have ties with any universities in Malaysia.
*NANOMALAYSIA SDN BHD	Not a manufacturer/sole distributor of any nano products. Does not conduct nano R&D. Only facilitates/acts as the third party in the communication between industry and academia and other industry players in the field of nanotechnology. Set up to drive commercialization of nanotechnology. Their web site is still under construction.

Source: Detailed study on company websites and through visitations; MTDC list of CRDF Recipients; * Exhibitors at Nano Expo Summit 2012

In addition to this, it is important to note that many professors and researchers are not yet actively playing a dual role in both research and commercialization. There is no doubt lots of research is taking place in universities, but the realization of these prototypes into innovations have not yet taken effect.

> ***AA:*** *One way to look at it is that companies have not yet taken an interest on local universities' inventions. The other reason is that companies are not prepared to take up such a technology, which will only show long term promise and no immediate returns. It's just too risky.*

This finding does not imply that there are surplus inventions produced by universities. However, it does imply the possibility that the research, which is taking place is not bringing out any commendable applications – applications that can trigger companies to take up such a technology due to the lack of reciprocation to market needs. It is also important to note that while there is no monopoly or any barriers for entry for nanotechnology, yet the number of nanotechnology firms remain very few.

> ***AQ:*** *In industry, SMEs are no exception. The agenda is to make profits; and make sure that this is achieved within a shorter period. In addition, lots of SMEs are financially not strong. Figuratively it is like a "small boat going into the middle of the ocean.*

This finding indicates that SMEs endure a rather challenging financial journey in midst of giant companies and also points out that profits that take years to yield will not be tempting to SMEs. The finding also clearly expresses that where the money is; that is where the SMEs are.

> ***AD:*** *Incentives will serve as some kind of buffer from the government to spur SMEs to engage in nanotechnology. But not all are knocking the doors of the Ministry of Science, Technology and Innovation because incentives are not made transparent. Many are not aware whereas there is a lot of help waiting. But it is untapped.*

Another obvious aspect is whether SMEs are truly ready to take up nanotechnology as a business outlook. Nanotechnology is more high tech than biotechnology. Majority of SMEs in Malaysia are involved in the 'keropok', 'dodol', mats, handicrafts, personal care, food products, natural products such as tea that don't entail high technology. However, this is not state that all SMEs are low technology. There is the existence of high technology SMEs as well.

> ***AU:*** *But the initial investment is too high and the financial risks are even higher. The return of investment is lower and the main idea of business surrounds entirely on the needs of the people. Nanotechnology suffers from that syndrome. It's an uphill battle.*

Nowhere do these findings indicate that the deficiency of knowledge is hindering SMEs from pursuing nanotechnology in our country. It also does not prove that they are not in a lack of it. They may be equipped with commercialization processes such as distributing nano products. But in terms of R&D and manufacturing, SMEs will need to engage in university collaborations that are rich with a bank of human capital. But whether or not SMEs can meet the expenses of employing technical capabilities and know how in nanotechnology is questionable. At the moment, solitary survival of a SME in nanotechnology will only paralyze its business existence and lifetime.

5.2.4 Adaptability and compatibility of nanotechnology innovations with existing systems

The thing with nanotech innovations is that they are usually comprised of new materials that have very promising technical yet intricate characteristics often never seen before. Several interviewees commented that nanotechnology innovations can be produced as standalone applications.

__AC:__ Just like the Magnetic Resonance Imaging (MRI) technology which is strongly dependent on the availability of the high field superconductivity magnets, nuclear magnetic resonance spectroscopy and computer imaging, nanotechnology innovations must strongly be dependent on complimentary technology factors.

These findings state that nanotechnology innovations need to strongly acclimatize with other systems. Further findings indicate that it cannot be generalized.

__AB:__ One of the easiest ways to penetrate nanotechnology would be "non-intrusive". When it comes to MRI technology, people find out whether they have an ulcer, bumps, and foreign lesions on the body through an endoscopy. It's basically about placing a very thin, very flexible and long piece of fibre optics. But it is the tip of the fibre optic that is doing all the work. And to be less intrusive as possible and to increase sensitivity, what they need is nano fibre optics. This nano fibre optics plays an important role in imaging.

__AG:__ In the case of the drug delivery system, in the stance of cancer for example, there are two (2) levels: One is the identification of the tumour and the other is the curative and therapeutic. In both aspects, nanotechnology comes into the picture". Some call it drug delivery system but I call it "control delivery system".

The reason for this finding is that medical researchers refuse to just deliver active molecules but they also want to control it.

> ***AA:*** *Control because we don't want to stop halfway. We don't want it to do some uncontrolled chemical reaction inside the body. We want it to do in a selected way by going into the side where the cell requires help and fix it.*

In other words, this is precision delivery. It is delivery but also with precision and control. Only a medical researcher can dictate when it should be active.

> ***AX:*** *The only way to do it is via nano. There is something that acts as a carrier or a substrate. The carrier has to be compatible with the inside of the body – anything that the body can accept that can serve as a platform.*

Furthermore, people have the right to know what goes into their body. In this context, knowledge of knowing what nano is very crucial. However, this does not indicate that nanotechnology innovations cannot be produced as standalone. It most definitely can.

> ***AU:*** *Generally, it has to be incorporated into an application. But it also can be created by itself for that particular application. Meaning to say, it can be a standalone technology that is tailored specifically towards a certain application".*

AG: *It depends on the field. For example, in the field of cosmetics, nano lotions and nano powders can be regarded as standalone technology. Therefore, the only system that it needs to get acclimatized with is the human integumentary (skin) system.*

Whether the innovation serves as a standalone or whether it needs to be acclimatizing with other systems in order to demonstrate its significance or built intention, the key knowledge, proficiency and know-how of specialists in this subject are indispensable when it comes to getting acquainted to using the system, preserving, controlling and troubleshooting nano associated problems. In other words, subject matter experts should be the master of the 'why' and 'how'. This applies to all aspects of the economy; whereas the public needs to be made to understand the benefits, durability and robustness of these technology innovations more than 'why' or 'how'.

5.2.5 Interactivity and knowledge absorption in academia towards creating awareness in nanotechnology

The palpable deduction that could be made on the subsistence of nanotechnology, arises within the element of what it is prescribed as a "known technological presence" as in how many people can presumably feel the manifestation of this technology in their everyday lives principally in communication. The current nanotechnology milieu is readily set for scientists and researchers within the R&D boundary considering that it has become a scientific piece of intriguing study and research in universities but is little known to those who inhabit outside this boundary. The external inhabitants of this boundary are presently incognizant of the true derivations behind the term "nano" but this does not imply that these external boundary inhabitants are entirely detached from its current effects and discoveries, which have indubitably deployed its presence through internal boundary innovations. Thus, this statement implicitly scions, either the notion that these external boundary inhabitants are consciously or unconsciously benefiting from these nano-based innovations.

> ***AG:*** *Not many will know what nanotechnology is. They will relate nano to its diminutive size. That would be the first thing that will pop up in their minds.*

The above statement echoes the fact that the term “nano” triggers the non-technical mind as a mere buzzword that has been absorbed through cinematic sight either via fictitious movies featuring nano-androids in the battle between humans and nano humanoids set in the futuristic end of civilization or via the visual identification of product labels bearing the name “nano”. These can be logically construed as “picked up” information, which can often be classified as a non-accurate personification and understanding of the technology. For one, the battle between nano-humanoids and humans in the war towards the end of civilization portrays nanotechnology as destructive and perilous to mankind; whereas product labels bearing the name of “nano” do not necessarily mean that it contains any percentage of nano components, as there has not been any law prohibiting the use of the term “nano” if ever it is not part of its product containment.

> ***AX:*** *The key about nano is because of the interesting physics of characteristics that come about it. However, those details, the general public will not know.*

The above statement incessantly places an emphasis on the verity that the public is oblivious of the other interesting facts surrounding the technology. Communiqué on the topic will be rather handicapped since the gen circumventing this technology remains to be limited within the realms of the internal boundary environment and cannot be easily flowed into the external boundary environment due to the deficiency of scientific understanding and visualization and also for the reason that there are very few individuals practicing this technology within the external boundary environment. Hence, the external boundary environment will less appreciate the essence of information derived from the internal boundary environment unless the popularity of nano benefits upsurges to the extent where nano innovations overflow the commercial arena. This can be further elongated to state that the external boundary environment will have less use of such information unless nanotechnology awareness upsurges to a level where "not knowing" will never be a given option. The cognitive visualization of nanotechnology will not be able to transcend beyond the mere layman level of intellectual capacity, which for the time being interprets nano as simply small, unless there is an insistent interest to dwell deeper into the subject using existing means of informatory tools.

> ***AB:*** *In the university, interactive learning generally transacts between the student and the lecturer; whereby lecturers' give lectures and students listen and participate. Another one is tutorials. In tutorials, lecturers supply the questions and students engulf themselves into a series of discussions with the lecturer. That is a two way process. We refer them as active learning and cooperative learning whereby whatever knowledge the students' absorb*

from theory and lectures, it will be applied and functionalized into their intellectual discourses.

What is being implied here is that, if two-way interactive learning were to transpire on the subject of nanotechnology, it will necessitate one of the two or more individuals to have sufficient, if not adequate knowledge of what nanotechnology is, in order to impart the matter on to their counterpart to ensure the transfer of accurate and unscrupulous information. This two way interactive learning within the external boundary environment infrequently takes place compared to the internal boundary environment where R&D is part and partial of the university arena unless there has been efforts to integrate this subject within their school curriculum. The above statement evidences the typical two-way interactive communication between student and lecturer, which instil the modes of listening and participating in tutorials, which sequences, the student's mind to apply theory into practical practice.

AX: *In the case of nano, interactive learning can be put in practice when a student is asked to problem solve a real time nano related bottle neck; and is requested to present their solutions before the whole class so that to create a Q&A environment at the end of each presentation.*

Nevertheless, this further reinforces the notion that this form of interactive learning can only be successful if one of the parties (at least) who is involved in this information interchange is knowledgeable of the concept of nanotechnology and is able to impart their understanding of the subject to their counterparts. Problem solving bottlenecks on nano related issues is something that generally transpires in the internal boundary environment where nanotechnology is currently pursued as a subject within the Master or a specialization within the PhD curriculum. Therefore, this form of scholastic interactive learning can only on the odd occasion transpire within the external boundary environment through scholarlistic visitations by professors or educators invited to spread the word on nanotechnology in schools. Nonetheless, this form of accurate and unscrupulous interactive learning does not include the coverage of the working class public.

> ***AU:*** *There are demonstration kits that operate as nano teaching tools which are available in the market that would facilitate in giving a fundamental understanding of what nanotechnology is. But there is not much awareness out there to incite and stimulate the public to go out and purchase these programs.*

These nano teaching tools benefit those who only have been incited, stimulated or propelled to explore the subject further for a precise reason. Self-awareness generally "sits in the last bench" of all probable reasons, because self-awareness can only emerge when adequate information has to some extent netted the receptiveness of the public who will be incisive enough to ask the 'why's and 'how's regarding this technology. This is why the public is neither sentient nor responsive to this subject - because only scarce know.

> ***AA:*** *The public is very "interesting". In the sense, that if you try to educate them or tell too much, it could backfire. Meaning to say, they will lose*

interest and get distressed for nothing. As a result, market acceptance will never subsist due to the fear of the unknown.

This finding does not entail that the public should not be educated on the topic of nanotechnology; however, it suggests that public awareness should be given precedence, whereby the public should be sufficiently well informed in order to understand that nano is not entirely dangerous as what people may perceive it to be. This is because there are profuse potential benefits that the public can appreciate from if only the information of nanotechnology is not being misconstrued.

5.2.6 Debuting nanotechnology in preschool level

Making sense out of something that have been made familiar through communication and practice, whether it has been consciously or unconsciously absorbed through years of schooling and after school, creates a sense of sentience and responsiveness towards the minute things that shape most parts of our lives. Most of these things are moulded from the beginning of childhood since instilling something new and futuristic are easier done when young compared to when they are older. Yet, matters concerning science are far more easily infused through scientific games and playing tools compared to the mode of imparting them through a syllabus that requires a more mature visualistic mind.

AD: *It's possible to get this topic across to a bunch of secondary students. However, to communicate it to kindergarten (pre-school) students - it will be quite difficult.*

__AX:__ To verbalize nano in a manner that is easily comprehendible to kindergarten students will be an arduous task.

Transmitting a substance matter as eclectic and subterranean as nanotechnology premeditates the need of duteous forecasting and design in the pre – school program of study even if the subject recipients under focus are just pre-schoolers'. Envisioning the formation of a hybrid group of individuals should be embedded during the stages where inculcation is found to be the easiest. Nevertheless, the procedural course development of aiding preschoolers' to process information that is found to be mentally challenging even for secondary schoolers' yet alone undergraduates will be something out of the ordinary but worthwhile in the long run due to the growing possibilities of conveying science through other mechanical tools which have a successive history of capturing the attention of young minds in the past. The findings do not imply that it is impossible to implement the conveyance of nanotechnology to pre-schoolers and neither is it ensuing that it is highly conceivable to perform such an implementation. However, it stresses the vulnerabilities that will arise in verbalizing nano in words coherent to pres-choolers'.

__AG:__ There still remain several challenges within the learning system whereby students continue to have quandaries trying to distinguish between 3D objects such as the prism, sphere, cylinder, cone or a pyramid with a square base. So to expect students as young as pre-school to identify with nano atoms and molecules, will definitely need something that is avant-garde.

Several of these responses proclaimed that it is possible to “push” nanotechnology into a very interactive manner in secondary schools but too premature to penetrate into pre-school. Thus, these findings can be sufficiently justifiable to derive an insinuation that there should be a model constructed to guide how pre-school nano teaching and learning techniques can be entrenched within the education system.

> ***AX:*** *The curriculum has to be extremely creative.*

> ***AU:*** *One way would be to expose pre-school students to nano based products such as nano games with the intention that they are unknowingly directed en- route to that area. It is an acknowledged fact that children have high inquisitiveness power to test something that is alien and new. Hence, if it is some kind of a nano game for instance, subsequently they will able to open up their minds to a whole new knowledge of nanotechnology.*

Furthermore, other heedful steps need to be put in place before one can introduce “nano” into the pre-school curriculum.

> ***AI:*** *You have to initially establish the theory of “micro” in the minds of these pre-schoolers; only then you can introduce the concept of “nano”.*

These findings indicate that albeit the intricacies and difficulties of expressing the subject matter of such technicality to pre-school students, the notion is not entirely impossible. A module can be constructed whereby it will not replace any other forms of pre- school learning but will serve as an expansion to the existing curriculum. Nevertheless, this will entail a very imaginative, inventive and resourceful group of individuals to graphically illustrate the size of nano and its prospective uses in an abridged way.

5.2.7 Embracing the opportunities of nanotechnology among non-research universities and colleges

Non - research colleges and universities are defined as educational institutions which do not offer research programs to their students and whose concentration is mainly in coursework. Habitually these universities will consist of a series of diverse undergraduate programs or MBA programs. Nevertheless, these universities do not proffer any PhD programs or MSc programs since these educational programs are heavily research based.

> ***AB:*** *There is not much activity that they can get involved in terms of research, obviously. But in terms of awareness and knowledge, the result of nanotechnology research can be explained to them in the attempt to impel students to pursue a Master's degree or PhD degree that which has an emphasis in nanotechnology in another university if they so please.*

The finding acquiesces that nanotechnology is intensively research based and that which succumbs mainly to the fields of physics, biology and chemistry involving experimental endeavours' but does not in any way justify that non-research colleges and universities cannot partake in nanotechnology non-research activities. Not all activities need to be research based. Albeit the inclination of research based universities towards innovative and result oriented outputs which are newly derived and original based on quantitative and qualitative experimental data, the up to date knowledge produced and accumulated from research based institutions can continuously be selectively diffused into the non research curriculum through the offering of an undergraduate subject on nano to suit each undergraduate programme. The selective diffusion embedded within the likes of each non-research undergraduate program can lead students towards a multispectral view of nanotechnology from various disciplinary angles that which transcends beyond mere scientific intellect and spur the demand of students to pursue a Master's degree or a PhD degree with a weighted emphasis on nanotechnology.

> ***AC:*** *There could be units or components constructed within their non-research curriculum which does not necessitate any high tech facilities or other nano related resources such as human expertise.*

The finding clearly scuffles the necessitation of high-tech experimental facilities and equipment as they will not be required in the case of non-research colleges and universities but the finding does not in any way infer that other graphical and visualistic handmade models cannot be used to boost the cognitive learning of nanotechnology in classrooms. The units or components constructed within their non-research curriculum will entail the aid of constructive and educative man made representative models of atoms and molecules, as a minimum, to demonstrate to non-research students, the phenomena such as surface tension/properties, quantum effects and molecular assembly via a streamlined modus. Nevertheless, this will require the human capital with rudimentary acquaintance and familiarity of the sciences to perform these demonstrations understandably and effectively.

AA: *The importance of nanotechnology can be delivered through visual effects. The visual effects could demonstrate the change of color using certain nano chemicals to indulge the students about the effectiveness of nanotechnology and help them perceive the purpose of nanotechnology without having to use electron microscopes.*

The above finding further fortifies the actualization that the solicitation of visual effects in the dissemination of nanotechnology information can empower the possibility of non-research oriented students pursuing non-scientific oriented programs by attaining an over the surface if not thorough connection with the scientific oriented subject matter without the use of high tech equipment.

AU: *There is a possibility that they can construct a course on the subject 'management of nanotechnology'.*

Gaining the immersion of non-scientific disciplines to envelope themselves within the subject technicalities of nanotechnology can efficaciously come into effect, not because these disciplines would gauge nanotechnology through the lenses of scientific interpretation, but they would be able to assess nanotechnology through their own non-scientific mind set, philosophies and opinions, which can aid in transcribing the complexes of scientific interpretations into simplified construal elucidations from the stances of the arts, economics, humanities, business, history, health and environment. It is from these stances, which will seize the interest of the non-scientific individuals to partake in the happenings and undertakings of nanotechnology. This philosophy of learning nanotechnology through multispectral discernment can be infused into the non-research curriculum as a subject known as "management of nanotechnology".

> ***AE:*** *They will not be able to produce or generate any new discoveries or knowledge in nanotechnology because they lack research methodology skills. In that aspect, there aren't any prospects. The subject of nanotechnology cannot be conveyed in a very comprehensive way.*

The finding above articulates uprightly that the deficiency of research methodology skills in non-research universities and colleges will paralyze the possibilities of any future prospects for interested graduates vying to compete in the field of nanotechnology. However, it must be taken into account that this finding connotes only to the circumstances surrounding non-research universities or colleges, and even though the facilities, university course syllabus and human expertise do not blend in with the possibilities of conducting research, it does not in any case thwart the graduate from forwarding their accumulated yet immature knowledge, absorbed from their non-research university to another research university which will offer better prospects to their field of interest. This is what takes place in the case of many areas of academic interests and the same scenario can also be presaged to that of nanotechnology.

Overall, these findings do not in any way indicate that the opportunities surrounding nanotechnology cannot be embraced by non-research colleges and universities, but indicates that at present, the subject of nanotechnology cannot be clinched comprehensively by non - research colleges and universities considering that it is still heavily research based.

5.2.8 Strategic partnerships and long term sustainability of nanotechnology on patents and publications

The yield that stems out from a collaborative double or triple entity formation is subject to factors, which do not guarantee instantaneous fulfilment of objectives and the core mission of the collaboration. Yield is a segmentation of various stages of collaborative output, which when amalgamated becomes the final stage outcome of the collaborative partnership. Nonetheless, every U-I research collaboration is subjected to a time-frame, whereby if the necessary deliverables are not achieved within the stipulated period, then the partnership is said to have failed in its mission and perforated its core purpose of its establishment. Yet, if it is the other way around, whereby the necessary outputs are achieved within the definite period, then the partnership is said to have met the needs of its mission statement and is esteemed as a euphorically acclaimed success, considering the amount of defiance that was faced to get to that juncture. The collaboration, which personifies the dual performing roles of both university and industry, is individualistic in their endeavours and priorities. Being an emerging technology, nanotechnology is a field that is heavily research based and therefore places the research driven entity as a major heavyweight in this partnership. In some developing countries, the core research driven entity lies within the realms of academia, where basic research on nanotechnology is still warming up itself; and in some developed countries, in which most part of it is predominantly confined within the realm of industry, where applied and commercial research have reached its peak.

> **AU:** *When academics do research on nanotechnology, it is not that they will come out with commercial product immediately. This is not logical or possible. There is a lot of spin off effect that comes out from any research program.*

The palpable scrutiny that can be germinated from any U- I collaboration is that the multi-phased transition that iteratively progresses from R&D, and that which flows fluidly into the processes of commercialization, does not anticipate for “fast track” results, which may only satisfy the notion of producing immediate upshots in the short term. Nonetheless, what is really expected is the process of circumventing the possible prototyping and production defects that can only be identified through the offerings of continuous re-engineering, which can deliver perpetual innovative success. The multidisciplinary field of nanotechnology represents itself as a field that cannot be pigeonholed with other technologies due to its atypical characteristics and complex technicalities. Its unsurpassed potential and notwithstanding the possible disastrous but preventable impacts are still surfacing through relentless investigations by researchers and scientists conducted during basic and applied research. The identification of the underlying effects within nano components and nano materials, either which could jeopardize or make the prototypes stronger is a time consuming process. Therefore, the processes involved in ensuring the sustainability of this technology has a lot to do with eliminating all possible illusions and misconceptions notwithstanding the fences that obstructs the technology from evolving further. Nevertheless, the knowledge of comprehending the amalgamation of scientific procedures involved in nanotechnology, which ranges from the knowledge of diverse scientific disciplines will sufficiently be equipped in predicting the length of time required for the execution of these processes; in order to meet the necessary outcome; and therefore, resulting in a foresighted U – I collaboration that can be administered to sustain nanotechnology. Nevertheless, while innovative and commercialized nano products are the proclaimed and anticipated end-results of any U – I partnership, there are other spin off effects that can be generated from it.

AQ: *First of all, these partnerships develop the expertise of the academician and for that matter, that particular university. It will provide opportunities in the sense that they train a number of students and send them off to industry. So the level of knowledge augments to a much higher level and the university and students would be able to take up more difficult challenges in the future. These intangible benefits will shift the economy technologically upwards. These benefits will come.*

The rudiments that arise in the form of market needs places the industry at its "mercy" and leaves the industry with no alternative but to incessantly trigger and impetus the role of academia in pursuit towards supplementing for the market opportunity that exist for that particular pre-prototypal invention, to the extent of assuaging the current consumer market environment. In the event of this ongoing perspective, the collaboration that spells out explicitly the requirements through prior arbitration and negotiation, propels academia to not only nurture experimental and cognitive researchers but to boost the recruitment of highly productive researchers from university to stretch and augment their capacity through sufficient scientific and engineering practice from the industry. Nevertheless, this manifestation is only possible only if the industry is regarded as a high tech industry, which is fully furnished with the state of the art nanotechnology equipment and also equipped with knowledgeable human capital from diverse scientific and management disciplines.

The primary purpose for emphasizing the term "high technology" is to fortify and maintain the position that if the nanotechnology industry is not regarded as "high technology", then it dispenses the verity that academia is the knowledge bank of human capital and the supply of highly productive researchers from university to industry will be only be a one way contributory channel flowing into industry rather than a platform to heighten the existing skills of the researcher itself. This phenomenon is what emboldens the protagonist role of a university to be connoted to that of a self-sufficient entity that will soon comprise their very own exclusive university spin off firms to run the commercialization process for the university. If a partnership is to be existent, both entities should be able to subsidize each other with their forte contributions whether in scientific or technology management in order to sustain the field of nanotechnology.

> ***AA:*** *The patenting issue also enters the debate. Patents are a sign that innovation has taken place. If there are many patents in the country, then some of them will become commercialized". Let's say if there are 100 IPs, only 5-10% gets into commercial production.*

For this to result, it is not merely or solely dependent on the strength and the knowledge of the research academician or the industry partnership itself; it is also contingent upon the market and the cost of converting the prototype into a product. A positive or negative deviation that either progresses or retrogresses the market dynamics, which revolves around the nanotechnology products consumer market is a result of fluctuating consumer requirements that arise from a resilient product competitive advantage that, which contemporaneously co-exists in the field of nanotechnology. Unless inventions have been prototyped in advance in conjunction with the needs of customer requirements, viable industry production costs and conceivable production mutability, patents are futile to the acuity of industry's commercialization of science but are seen as an affirmative augmentation to the researchers' academic performance index and university ranking system. These patents is a positive indicator that innovation has taken place but does not prove as a positive indicator that, that particular innovation will be 100% absorbed for the purpose of commercial development. Industry intervention that exists right from the beginning of the conception of its invention will enable mutual and shared patenting rights between industry and academia; that which will eliminate any incongruences pertaining to the "protective disclosure" of germane engineering and production information. Thus, "technoprenurial" knowledge of the nanotechnology consumer market and the industry production costs prior to any development of a nano prototype can stir patents (after reaching the post development stage) into the direction of commercial production. The "technoprenurial" knowledge that descends from the fastidious consolidation of science, technology and management disciplines embedded within the University – Industry (U- I) collaborative network will be able to ensure the sustainability of nanotechnology. After this comes the issue of time factor between research and commercialization of nanotechnology. This too affects the sustainability of partnerships in this field.

> ***AD:*** *It varies from field to field. For medical, it would take around 10 -15 years because they have to go through the health and clinical testing and acceptance. In contrast, let's say for biotech, oil and gas, it would take around 7 years. Even though, venture capitalist would want it to be 2 – 3 years, there should be all kind of help to make it to 3 years to reach the market. But 5 years is reasonable for most products.*

The number of years taken from R&D and commercialization is a measurement that seriously needs to be observed into. The challenges that contribute to this time factor mainly reside in the area of pre-commercialization or specifically pre – production. The emerging cordons that evolve from continuous nanotechnology research, interrupts the planned timeline, whereby bottlenecks that arise are given higher priority of fulfilment by scientists and researchers rather than fulfilling the opposite entities' proposed and expected finish timeline, which involves satisfying venture capitalist and investors. These emerging cordons are inexorable and are bound to take place but are solvable; yet, the duration of time required to resolving these impediments cannot often be absolutely prophesied, due to the inability to predict the intensity of these predicaments prior to the beginning of R&D. The level of intensity and magnitude of these predicaments is what contributes to the time factor. Furthermore, each process within the multi-phased R&D are closely linked and are inter-dependent; meaning which the unresolved bottlenecks that arise within each process will inevitably cause the consecutive processes to become unstable, resulting in the entire project to crash prematurely. The field of nanotechnology is not immune to these causalities; in fact it is more prone than any other existing technologies due to its intricate characteristics and physics of that size. The plausible repercussions that soar from the lack of understanding of these causal problems by the business entity can lead to a unidirectional yet ostensibly unreasonable number of counter – efforts that can only exacerbate the core purpose of the collaborative initiatives. In the milieu of nanotechnology, it is pertinent for the business entity to be represented by a cluster of nanotechnology savvy entrepreneurs to literally cognize (yet evading significant intrusion) on the outset of these outputs, which are expected from the R&D specialists in order to discretionally contradict or endorse/certify the trepidations that arise from the intensity of these nano R&D predicaments, and to ensure the sustainability of this field of technology.

> ***AX:*** *The public perception is nano safe. Sometimes the product may be ready for the market, but the market acceptance may not be there because of the fear of the unknown. It takes another group of people to work on the awareness, safety and health issues of nano products.*

The threshold of any prominent product offering is to embark towards the preliminaries of innocuous product utilization for the wellbeing of the potential consumer; resulting in market readiness being subjected to the absolute orthodoxy of safety regulations placed on a newly declared product prior commercial release. The public knowledge of nanotechnology is not to be overly estimated or taken for granted since the principal responsibility lies in the hands of the “product releaser” who declares the product as nano safe. Nonetheless, it also hinges on at what percentage (%) of nano component is embedded within the product itself which correlates to what kind of level of exposure and level of detriment it interposes itself to the utilizer. The processes that are required to conform to awareness, safety and health related issues of nanotechnology are multidisciplinary; in the sense that the impacts that unfold from different facets of its sub disciplines are different in nature and subject to various scientific interpretations; that which conclusively defines the level of hazardousness or non-hazardousness of nanotechnology products for consumer utilization. The predominant aura of these processes makes nanotechnology to be treated with added caution compared to other technologies due to the added thrust of negative ambiguities placed upon it; and thereby resulting in the augmented need in the level of awareness and extra stress placed on safety and health issues. The pertinence of these processes in the course of nano product development becomes the epitome and "central crust" of any U-I collaborative debate related to nanotechnology and thus requires its fullest consideration and responsiveness for the sake of its sustainability.

> ***AG:*** *It also has to do with the robustness of the technology.*

There are also the engineering challenges that can hinder the sustainability of nanotechnology.

> ***AD:*** *For example, in nano electronics, the difficulties endured when it comes to the nanoscale is getting the reproducibility in characteristics in the electronic device. To make one transistor to repeat with another transistor – in the sense to make it uniform, that is a technological barrier. This is because the physics at that size - is hard to get it very regular. It also depends on the workability of the technology.*

The element of product functionality lies within the cortex of its engineering ingenuity, which underlines the originality and uniqueness of each product identity. In the case of nanotechnology products, it is the nano embedded material or component, which authenticates a product from its non-nano product adversaries. Therefore, any nano prototype, which becomes the experimental output of scientific fields or sub disciplines of biology, chemistry or physics, is subject to undertake a series of engineering mechanisms. This series of engineering mechanisms are piloted during the development of the prototype and performed during the industrial production manufacturing, which is post R&D. During the development of the prototype, the engineering mechanisms are basically focused on only a single prototype per se. On the other hand, during the phase of industrial production manufacturing, these engineering mechanisms focus on mass production that eventually result in the reproducibility of a single prototype into many numbers. Therefore, the tangible challenge lies in the mutability of a single prototype that needs to adhere to the exact uniformity of the original prototype, which eventually burdens the stage of "product regularity conformance" due to the miniaturization of its nano scale.

> ***AU:*** *When you develop the technology, normally you come out with 2 – 3 prototypes, but when you go commercial, it has to be 1 million – 20 million. You need to have that volume. Production of large volumes is a challenge especially at reasonable cost and high quality.*

> ***AQ:*** *It is easier to make them at small scale but to make at a large scale would be difficult in terms of the reproducibility.*

> ***AE:*** *When you do a small number, you can control the parameter. You can make sure the performance is at a certain temperature; whereby you can "twig" (optimize) your recipe so that it will meet the requirements. But if you do one (1) million, you don't have all the time in the world to make sure that every single device is "twigged" (optimized).*

> ***AX:*** *It is the procedure that makes nanotechnology complex.*

There is a lot more physics that goes into it whereby researchers even experience certain processes happening outside the ordinary. Therefore, the researchers' knowledge, skill and experience are greatly needed to circumvent errors and to intelligently incorporate certain problem solving methodologies. The problem solving engineering methodologies related to nanotechnology are very much a "staple part" of knowledge within the R&D ménage to the extent of which, when gotten-to-grips with can determine the smooth transition of the R&D endeavour and rapidly cope with obtrusive protectorates that can plausibly cause the entire project to fall victim to. Therefore, the selection of an impeccable medley of trouble shooting engineers by key stakeholders of the U-I collaboration can precipitate the process of continual re-engineering of nanotechnology products and thus contribute towards the long-term sustainability of this technology.

Another aspect that needs to be looked into is the different priorities focused by both academia and industry. Partnerships will be futile if ever the priority of both academia and industry is moving towards two (2) separate directions. It is a known reality that for many years, that the academia's main focus was towards teaching and research where universities get recognized and the industry's forte is geared towards commercialization.

> ***AC:*** *One should not forget that the university is also another type of industry – an industry that is not only for the purpose of disseminating knowledge but also for "boosting up" the number of publications. They can do both patent and publications. But the universities need to give prominence to patenting. Let's say, the minute an academician patents an innovation, that itself should "short-circuit" 5 or 10 publications. If they don't have a patent, then*

they need to come out with 5 or 10 publications. But if the universities don't provide the same rating; then there is no incentive. It should be for instance, one patent is equivalent to 5 or 10 publications.

The role of university is personified as being involved in the production of research publications, which in part if not entirely have contributed to the commercialization process. This remains to be given a substantial amount of priority by academia and have been used as one of the performance indicators in the university ranking system and as stated in the earlier paragraphs, is to boost the academic's profile. Nevertheless, the cruciality of its offerings does not halt in the form of paper alone. A matter of fact its state of the art findings have also been converted into commercial reality. Nevertheless, this remains an area of less importance to that of the industry, which prioritizes more on commercial output rather than the act of collaborating to assist researchers to disclose pertinent findings in the form of publications prior to patenting and commercializing the end product. Such data revelations are disastrous to the mission of the industry, resulting in the industry and academia unwilling to see eye to eye in their own individualistic but egoistic priorities. This two (2) way opposite directional priorities is what disables the mere fortification of U-I collaborations and that which "dichotomizes" the notion of actual nanotechnology sustainability. This phenomenon interferes with the possibility of transition of nanotechnology prototypes into the realm of commercial production and eventually causes the transfiguration to lag behind and prototypes to sit in the shelves. Therefore, universities should be able to come out with a weighted equation that measurably communicates the ratio of importance of both publications and patenting in order to incentivize academics to place auxiliary importance towards patenting as compared to publishing or at equal footing. Yet, it will be challenging to incentivize let alone impetus the industry to demonstrate their flexibility towards academics to publish their findings, prior to patenting or commercialize their products. Nevertheless, both entities can reach a consensus to provide academics the immunity to publish their findings evanescently phase by phase via “stretching” the publication process until a definite sign of commercial output can be realized.

> ***AE:*** *Patent are normally into the application, design, composition and methodology; whereas scientific publications is more towards understanding.*

However, publications have been in some scenarios treated as an input for commercialization. Therefore, partnerships need to recognize the two.

> ***AC:*** *We cannot stop these processes from happening. If we stop these processes, we are stifling the creativity. The university research must tie up to solving the problem of the industry which is not state of the art*.

The relegation of either entity, just to toe the line to the needs of the other entity’s prioritized disposition will only jeopardize the existing structure of collaborative affairs. The existing processes that define each entity’s prioritized disposition predominantly and significantly distinguish what each of the party value the most from the collaboration. Therefore, these creative processes cannot be called to a halt. Once academia and industry decide to merge in a U-I collaboration, their underlying mission is one yet they try to ensure that their individualistic motives can also be carried out during the process. Meaning to say, academia and industry try to “get what they came in for”. From the perspective of the university, the university’s underlying aim should be to trouble shoot the complex problems faced by the industry through non-stop research apart from their “added spin off benefit”, which provides them the facility to publish their state of the art discoveries. In another line of argument, industry problems can excavate academia to move beyond from the traditional boundaries of their research and develop the expertise of the researcher and the university.

> ***AI:*** *If we leave the university alone, they will explore and study the 3-D or the 4-D or the unlimited dimensions of the problem at hand and then the industry will distinguish how it can be applied to them.*

Even though application research is the more welcomed stage of any kind of development research and one that is favoured by the industry due to its permeation of closely outreaching to the level of plausible product innovative realization – which is many steps ahead of basic research, it will be an absolute detrimental decision to disregard the role of basic research which currently and strongly resides within the wing of academia. Through continuous re-engineering during the process of applied research, there is bound to be bottlenecks that will eventually lead scientists and researchers back into the reiterative undertaking of basic research in pursuit towards further embellishment of intrinsic details that could vehemently “clear the passage way” through applied research. Therefore, basic research is as symbiotic to applied research as university is to industry when it comes to nanotechnology. The university is at a higher advantage of proficiently problem solving the dilemmas of industry due to the multi-selective array of multidisciplinary specialists who have undergone rigorous academic and professional practice who can converge and ruminate from the multi-dimensional assortment of scientific standpoints; which clearly and predominantly lacks the business acumen of an industrialist. Therefore, the need to acknowledge the former in the quest or in the forefront of triumphing the mission of the latter is germane to the sustainability of nanotechnology. The serious challenge faced by the industry in these partnerships is that,

> ***AI:*** *The industry is not able to leverage the knowledge directly from the professors in the universities. Therefore, what they will do is the market driven research.*

Nevertheless, if the universities were to work alone, they will not be guided by the market needs. Therefore, this win – win situation where both parties benefit from each other's outputs will ensure the sustainability of nanotechnology.

> ***AE:*** *The workers need to pursue a modular concept; whereby they are trained in a diversified area of nanotechnology. From the machine operator to the packaging expert or the marketer, they have different types of knowledge and know-how's. Therefore, the university should be able to put together a training module to suit these needs. However, not 100% need to come from university. When you develop a module of a product, it will describe the ingredients, packaging, manufacturing or costing. That way,*

both sides don't compromise their integrity and P&C. Meaning both academia and industry will need to educate their workers.

Diversified stream of educative training in nanotechnology, precursors the need to entrench different types of knowledge know how's within the industrial confinement of production activities, not just during R&D; resulting in the development of training modules that segmentally preambles the core information related to the smooth running of processes of nanotechnology post development by means of gaining a deeper understanding of the engineering manual specifications constructed during the development process. Both academia and industry will be able to synthesize together the modules, which are both knowledge based and industrial based in order to mutually educate both sides of the end streams.

5.2.9 Relationship between strategic partnerships and productivity in nanotechnology

In business, it is a general metaphor that we get repeated orders when we are carrying out the right steps in pursuit of getting those orders. If there is collaboration or a smart partnership between universities and industry and if everything is going well, the ties between the two parties stay as it is. There is no reason why it should dissolve.

AE: *If all is well and they are content, then, they don't look left or right*.

Unless there is an absolute justifiable basis to augment higher value to this collaboration or partnership, there will not be any need to disband the already congruent relations by both parties.

> ***AU:*** *If currently a corporation establishes close ties with University (A) who is proficient on certain know how, but not that proficient in another certain know how, then it is not that they cannot see left or right. They can.*

> ***AB:*** *There should be continual activity together.*

Industries are in a constant look out for parties that can offer ground-breaking ideas that can help them take their business to greater heights. This should be mandatory in any kind of U-I partnership. Continual activity merely means constant communication and productivity.

Another common problem in U-I partnerships between industry and university is,

> ***AA:*** *The university professor puts everything on the table. But the industry does not have the expertise to translate those findings into products because normally what you get from these professors are loads of data, graphs………..But how do you translate those data, graphs, information into something more tangible….into something that you can sell.*

Therefore, what the industry is in great need of is competency. One is hard work to make the U-I partnership continuously and productively working and the other one is the knowledge encapsulated within in each stakeholder of the partnership in order to benefit from each other's contribution. Furthermore, each output from the individual parties need to be periodically monitored. Once all this is properly entwined, that would be the right thermometer to measure whether these partnerships are actually outputting. It is more effective to have market penetration when there is a pull rather than a push.

> ***AC:*** *By viewing the industry as the off-taker, you can work in a push concept or a pull concept. If the industry identifies where exactly their need is, then the universities should work in support of these needs. That would be better.*

This finding implies that there should be less resistance rather than pushing. Rather than universities saying, "*Look, I have a nice prototype. Do you want it?"* On the contrary, the industry should approach to say, "*Can you work on this prototype that has this particular property in it?"* Based on these findings, the pull concept is much preferred than the push concept.

> ***AI:*** *In terms of its longevity once the product has been developed to a certain level and once the product has been taken up by a firm, then generally it's all dependent on the firm to drive it.*

The key findings amplifies the view that U-I partnerships are achievable and will protract on the condition that there is continuous and productive activity together between two parties.

> ***AD:*** *Nano research still remains to be only conducted at the university level. Initially, the development of nano in Malaysia was not directed towards commercialization but lately the government began to make an initiative to provide funding for commercialization.*

This finding therefore indicates that there is a precipice between research in the university and commercialization in our country. In support of this finding, a researcher endorses this statement by stating,

> ***AA:*** *Because in the university, most of the research is focused on basic R & D. We have not shifted our focus on to any particular product for a specific target market.*

> ***AI:*** *Malaysia has actually emulated lot of overseas research. Therefore, Malaysia has the capability in terms of nano. It's just a matter of forging all of it together into a product. That is slightly moving in a slow state. Initiatives carried out to make this all work has not fortified properly.*

These findings signify that the output of current research still remains at the prototyping stage. It also provides substantiation that the initiatives carried out have not been concrete in its endeavours. Meaning to say compared to other countries, the outputs have not augmented in parallel with the amount of ventures taken to convert a prototype into a fully-fledged product. Nevertheless, through recent evidence; the trend seems to be gradually migrating from prototype specific to product specific.

> ***AQ:*** W*ith the advent of commercialization funding, researchers have switched their approach from conducting university-based research towards working in the direction of generating products that can be marketed.*

> ***AI:*** *At the beginning, the gap that would have taken from 5 to 6 years between university research and commercialization then; has grown lesser now.*

In contrary to these optimistic, affirmative yet pragmatic findings, there have been observations that divulge scenarios whereby in some cases many universities who come out with prototypes which ultimately do not get commercialized.

> ***AG****: It is a matter of cost actually – the cost of processes. That means the method to make no matter what prototype or material, if the cost is high, then many companies are not willing to pick up the technology until the cost can be brought down.*

However, the cost is not the single most cause of why many prototypes have not been transformed into products. There is another relatable reason as to why these transformations are not taking place.

> ***AA:*** *Universities are not being guided by market needs.*

This does not imply that universities are "blindly conducting research".

> ***AB:*** *Because universities are moving in the direction where they want to get recognized. To get recognized, they have to do good research. Priorities between industry and academia are different.*

This is not to say that universities are not making any effort in pursuit of solving this dilemma. Several universities have set up their own divisions to look into the Intellectual Property (IP) and technological related ideas. Still, there seems to be a void that exists between academia and industry.

> ***AI:*** *You cannot entirely say that it's the fault of the university because most industries in Malaysia are still not very high tech.*

This finding paves way to a contrast to other developed countries whereby big industries have excelled in R&D through the convergence between industry and academia. Compared to companies overseas, industries in Malaysia in general are not very strong in nanotechnology R&D. This is because these giant foreign companies have excelled in the research establishment since a very long time.

> ***AX:*** *Shell Global and all the other giants are very strong in R&D but Shell Malaysia is close to nil in the R&D of nanotechnology.*

Shell Global is currently looking at alternative energy as one of their green initiatives and nano materials are said to be embedded into this alternative energy. Joining Shell are also other companies like Exxon Mobil, Talisman, Murphy, Petrofac, Carigali Hess, Newfield and Motorola who have not yet ventured into the field of nanotechnology. But companies like Hitachi, Sharp and Philips have infiltrated their way into the field of nanotechnology. However, PETRONAS is one large company in Malaysia who has penetrated into the field of nanotechnology.

AA: *Yes, there have been some efforts and initiatives taken by them". In fact, the company has invested in a centre known as COINS situated in University of PETRONAS (UTP).*

AX: *University of Malaya is in a much stronger position in terms of infra and human capital.*

This finding does not suggest that other universities lack desolately in both these components but implies that University of Malaya has an added edge in terms of advancement. However, it must be affirmed that no specific figures have been disclosed to authenticate this finding explicitly. But what is obvious is that the competition is in the rise in the field of nanotechnology.

AA: *In terms of Intellectual Property, MIMOS being a research institute, is in the forefront in MEMS and nano. In addition, we want to work closely with universities so that we can tailor it in getting a product that is well suited.*

Currently, MIMOS is working with UKM, UM and UiTM. But whether or not MIMOS wants to work with universities in terms of basic R&D or is prepared to just to take the prototype that is ready on the shelf,

> ***AC:*** *It's more of the latter. They are actually willing to take the prototype that is functioning and what they do is convert it into a technology. That is the Modus of Operandi in MIMOS.*

This directly implies that basic research is not the forte of MIMOS.

> ***AI:*** *We do collaborate. Basic research is done by the universities. Our concentration however is in applied research whereby we have the infrastructure to build up until the device level. But we still need to incorporate the fundamentals into it. As you know, fundamentals need time to improve. So we do have the first generation devices which we test but ultimately it's the second generation devices that we will use.*

This research institute is currently looking at mostly sensors containing nano materials that are light weight and that can also serve as a complimentary technology product (combined with other products). The benefit of incorporating nano materials into these sensors is to cause it to be more receptive to even the slightest change compared to any other sensor. For instance there are these incremental miniaturized sensors which are low in power consumption and do not always require the power to run. Existing door sensors like the Ingersoll Rand (IR) which is considered to be a security technology is still very high in power consumption. Therefore, these miniaturized sensors have been targeted to replace this technology for even a cheaper price.

In terms of how many of MIMOS's products are out there in the market, a researcher states that,

> ***AA:*** *There is only one (1) in the market and they are the MPK sensors which are considered to be more nano related. The others are still undergoing research.*

These sensors are mainly devised for the purposes of the national benefit especially the plantations in Malaysia.

5.2.10 Synchronization of principles and standards in the development of a R&D policy for nanotechnology

At this point of time, nanotechnology has been found to be dispersed within various industrial sectors; given the fact that nanotechnology is currently a multi sectorial technology and has not been made a single industrial sector *(not a stand-alone sector)* classified under Nomenclature Generale des Activites Economiques dans I`Union Europeenne (NACE), US Standard Industrial Classification System (US SIC), United Nations Standard Industrial Classification System (UN SIC) and the North American Industry Classification System (NAICS Canada). NAICs includes 1,170 industries and SIC includes 1, 004 industries. There are 358 new industries recognized under NAICS and 250 of service producing industries (Department of Revenue Washington State, 2010). It has been identified that 800 over nano related firms are associated to 40 NAICS codes. That is why nanotechnology has not been incorporated in its key findings by statistical organizations worldwide as a specific industry. There is no industrial classification that exists for nanotechnology. What is available are only the general and standardized censuses carried out annually which adheres to the following international classification systems.

Nonetheless, under the International Classification System by the World International Patent Organization (WIPO), nanotechnology has been acknowledged as a field of technology converged with microstructures under the technological wing of chemistry.

> ***AG:*** *Because the impetus and stimulus to synchronize under one sector has not yet surfaced. It also depends on the advisories of each country and whether they gain strongly from nanotechnology becoming a single sector.*

Furthermore, in support of this finding, another researcher adds on.

> ***AB:*** *In some countries, the impact is not clearly seen and realized from the well-being of society and the economic industrial growth of the country. Due to this, the initiatives and efforts have been marginalized". If you were to measure the amount of development of these products worldwide - there aren't many. Therefore, there are no constructive grounds hitherto to declare it as a distinct field.*

> ***AX:*** *For instance, if a biologist invents a radical bio embedded nano product, the biologist will declare that it is a product to be assimilated into the field of biotechnology and not nano.*

Notwithstanding that nanotechnology does not belong to any single field (denoting that not a single science field can claim its annex on this technology); it still remains an extension of various sciences.

> ***AQ:*** *Nanotechnology still remains a hype that is yet to deliver gauging results. Thus, the only way to proclaim nanotechnology as a standalone sector is a lot of activity needs to take place surrounding this field. In other words, the commercialization of nanotechnology needs to thrive in order for a standalone nanotechnology sector to come into sight.*

Therefore, these findings indicate that presently, the governing body need not create and enforce policies vis-à-vis it's R&D and there is no qualified need to call for a confederacy of R&D policies and procedures concerning the multispectral nature of nanotechnology.

5.2.11 Extensive pool of knowledge embodiment and multidisciplinary nature of nanotechnology

Nanotechnology has been acknowledged as multidisciplinary due to the extensive yet diversified nature of scientific combinations found characterized within its milieu; thus distinguishing it as a broad ranging field of S&T. Within the demesne and magnitude scope of nanotechnology, one can begin to permeate into the area of wide focuses, which includes the original sub fields of Biology, Chemistry and Physics, and then further advance into mainstream fields by undertaking a minor in nanotechnology. For this to consequence, nanotechnology needs to be offered as a minor subject either during the university undergraduate or graduate programs. The curriculum should also include elements of Mathematics, computer modelling and the engineering of nanotechnology. Based on several experts' interviews conducted, one of the questions posed was, "*How would students address something as wide and comprehensive as nanotechnology*?" which is rather a difficult area to address at present.

> ***AB:*** *If person A were to know the subject of Chemistry and lack the proficiency in the subject of Physics, whereas person B were to know the subject of Physics and lack the proficiency of electronic engineering, there will be a void. Hence, in the effort to expunge the existence of this void, balancing will need to conquest.*

This is possible only if a student were to have the strong fundamentals related to the field of nanotechnology. Without the fundamentals, one would not be able to relate to this very complex field of technology. However, students do not need to know nanotechnology in a wider and comprehensive sense, as it will disable the student from contributing to a specific topic later on. Furthermore, in order to contribute to nanotechnology in a specific topic, he or she will need to have very robust fundamental background in relative sciences; and not an advanced background in all relative sciences. Nanotechnology scientists cum academicians will need to educate their students in relative sciences in a strong way while at the same time keeping them abreast of the possibilities of not only using his or her absorbed knowledge, but also enabling the expansion to a higher extent. Nonetheless, in this aspect, rigidity should be greatly circumvented to avoid dread and trepidation from creeping in within the subject matter. Nevertheless, when it comes to the delivery of nanotechnology as a subject, the approach will be rather different for all three levels whether it is for undergraduate, Masters or PhD studies. For PhD, it is more focused, whereby students only dwell into a small area of study. But, for the undergraduate degree, it is considerably different whereby a student will not be able to “cover everything under the sun”. Therefore, the curriculum should cover specific mainstream subjects like Biology, Chemistry and Physics and offer a minor in nanotechnology. After the completion of these fundamentals and a minor in nanotechnology, it will still be difficult to reach an assumption that a Masters student would be able to coxswain directly into the realm of pure concentration of nanotechnology. Thus, this strongly depends on the field and what he or she wants to do next. It also depends on how much of coverage has already been done and how much a student is familiar with to carry off a complex field like nanotechnology.

> ***AA:*** *In schools, students are already exposed to science subjects. However, when these students enter university, for instance, a student enters into the Department of Physics to study Physics; and clearly, the student can't enter all three (3) departments such as Biology, Chemistry, and Physics simultaneously which would be downright unmanageable and impossible.*

Nevertheless, a student can enter into the Department of Physics and major in nanotechnology from a Physics perspective or if a student enters into the Department of Biology, he or she can major in nanotechnology from a Biology perspective. At a Masters level, a student can learn about quantum mechanics and atomic bonding; but ultimately only at a very certain depth. However, if a student were to enter into the field of nanotechnology, he or she cannot absorb the entire syllabus of advanced Physics and Chemistry. This is highly improbable. Therefore, this is the time, whereby the student will be necessitated to focus on a specialization since it is highly plausible for a student to undertake a subject like nano-chemistry or nano- mechanics. That is why nanotechnology cannot be regarded as a standalone discipline. It is merely an extension of all the other existing disciplines. Keeping this in mind, this proclamation cannot be taken as absolute since the field of nanotechnology remains a frontier yet to be experimented and its educational possibilities have yet to be explored. This means, nanotechnology may not possibly be regarded as a standalone discipline but there is no evidence to suggest that it cannot not be regarded as a standalone university program. There is a clear distinction between the two. Even though this study of the nanoscale has stretched its wings from various sciences, however, until today, no educational field can claim its ownership on nanotechnology for the reason that nanotechnology does not belong to any solitary field. Furthermore, for the production of a hybrid expertise in the subject of nanotechnology, the knowledge of this technology should be deeply embedded into the education system, whereby it becomes continuous. It should not be confined within the sole solitude of the university level system. Meaning, it must establish itself within the realms of primary and secondary level of education.

> ***AG:*** *Hence, that, if a student were to learn the subject of Chemistry for example, let's say in the first three years of secondary education, they learn that if they add a certain chemical particle, the colour will change from white to blue to green. The first level is through observation and later they connect that observation to a simple deduction. The same thing is repetitive in the fourth year of secondary education whereby the students begin to look into the complexity of the chemical particle or substance. For instance, when copper is neighbouring with sulphate, it will give a certain colour. If copper is neighbouring with nitrate, it will give a different colour. Therefore, this is "complexation chemistry".*

Now if a student were to go to university, the same thing is repeated but a different approach toward learning nanotechnology is absorbed. This time they will look from the perspective of quantum and hybridization. For instance, what makes copper "like" sulphate and so on". This means that the smooth progression from one education level to the next leads to the deeper reasoning of what nanotechnology really is. Thus, it cannot be left with the university alone. They have to "walk, run and jump". All this needs to be done in tandem. Consequently, the awareness and excitement should be built at the school level. Based on these finding analyses on the production and development of hybrid expertise, a question was posed as to, *"What if the university constructs a nanotechnology curriculum specifically for undergraduates whereby it will guide students from the perspectives of Biology, Chemistry and Physics. Will that be good or bad?"*

This will definitely be unadvisable because students will know little about everything and will not be able to contribute to a single field appropriately. However, the situation varies after a student has completed his or her Masters training. By then, they will have the maturity to pick up the knowledge effortlessly; whereby, whichever science disciplines they pursue, they can ladder up to nanotechnology.

> ***AX:*** *If a student is a good physicists or a good mechanical engineer, he or she can pursue nanotechnology. This should be the way at least for the time being until something revolutionary happens.*

Therefore, even as a PhD who knows the in's and out's or minutiae of research methodology, he or she will be able to pick up the different sciences. That is why, if an observation is made on several lecturers who have targeted a specific field, they have the potential to switch into another field but require time to slowly adapt. Even though specialists of various sciences congregating to work on a single prototype may bring about innovations that prove to be beneficial, but at the end of the day, it is all about different frequencies and wavelengths.

> ***AD:*** *When physicists were to talk to biologist, they will have trouble understanding each other or vice versa. However, if a chemist were to talk to a biologist, it is a little better because it's still physical science.*

Nonetheless, between biology and wide ranging physical sciences, there is a slight challenge to communicate in the same frequency. Engineering, medical, dentistry, pharmaceuticals are all beneficiaries of nano. Engineers are less strong in science but they are indispensable because they are greatly required to engineer prototypes whereby they need to package all the specifications into one single system. In this scenario, the science based individuals need to communicate with the engineering based individuals. In terms of application areas, for instance, in the design of the semiconductor light source – which is the Light Emitting Diode (LED), if a researcher were to understand the liking of the optical but do not understand the physical, he or she will not be able to engineer the device. The optical density of a medium is not the same as the physical density. Therefore, when it reaches to nanotechnology, a student can permeate deeper and deeper until they reach the nanometre scale, wherein the behaviours and characteristics are completely different. In the case of designing a LED for example, a student will want to know how and why 'light' is achievable, and for that, he or she needs to study quantum mechanics. Then, the student may have to go into Physics and study the behaviour of electrons. Later, they need to venture into Chemistry and study the bonding behaviours, which take a lot of understanding of various sciences.

AC: *To put it succinctly, a student have to "understand both the front containing the glass and the back containing the plastic and rubber". Nevertheless, if a student were to understand the glass and do not understand the rubber, he or she will not grasp the whole picture.*

Therefore, this is a solemn dilemma faced in the education of nanotechnology. It requires an amalgamation of various sciences put together to form a standalone nanotechnology program and it will be a difficult process to construct a curriculum to successfully satisfy these requirements.

5.2.12 Knowledgeable human capital for R&D and commercialization of nanotechnology

Hands on cannot substitute traditional classroom learning as there needs to be a constructive blend of both. Even though companies feel that the former is more contributory than the latter, that notion should never be universally acceptable. The preeminent way would be to exploit and explore all feasible yet practicable learning techniques in the field of education. By solely relying on hands on, it will merely generate people who are incapable of thinking larger. They will learn minute things but will lose sight of the bigger picture.

AB: *Experience cannot simply replace classroom learning and this is true not only for the field of nanotechnology. Hands on training minus knowledge accumulated from traditional classroom learning will take the field of nanotechnology nowhere.*

Those who wish to take their research to greater heights (meaning to a higher status), they will require a deeper knowledge about assorted aspects of nanotechnology. Only if they meet these conditions, they would be able to execute hands on or else they will replicate, duplicate and reiterate what other people have previously done, or else the phenomena will produce a whole line of technical workers rather than knowledge workers. This finding has been established from the facet of microscope utilization.

> ***AE:*** *If it's a simple optical (light) microscope; for example, an introductory biological compound microscope - then any student from elementary school will be proficient enough to use it. Thus, when it comes to the field of nanotechnology, one will require the use of electron microscopes such as scanning electron microscopes (SEM) and Transmission Electron Microscopes (TEM). For the use of SEM, it will require the basic background because you need to apply and interpret the results whereby a bachelor's degree will do.*

For the use of TEM however, a researcher will require higher levels of training to interpret the results generated from it. In this context, a Master's degree will be preferred. This finding clearly declares that postgraduate training and experience is paramount for the use of the TEM.

> ***AQ:*** *However, one cannot produce a person who has just learnt the use of a TEM from school to be an expert in TEM microscopy, because to understand the use of a TEM, a student needs in depth knowledge of*

Chemistry, Physics, Electronics and Mathematics. Therefore, it is improbable to produce a student who just finished school learning - to use microscopes.

It is probable to produce technicians but not researchers. In terms of maintaining microscopes, especially like SEM, there will be a need for a higher level of maintenance. There is back up service provided by the supplier but only to a certain level. Hence, there are different levels of maintenance involved. The technicians can carry out the smaller types of maintenance but the manufacturer of the microscope will execute those, which are not approachable by the technicians themselves. The manufacturers are the ones who define these maintenance levels. What is being stated here is that, it highly improbable to move beyond a certain maintenance level by themselves because there will be a risk of ruining the machine. Consequently, in that aspect, there is no alternative, but to leave the experts who built the machine to carry out the maintenance. Thus, these findings indicate that hands on learning cannot replace classroom knowledge learning and that the former must be anchored based on the latter. At the outlook, a complimentary relationship that links these two methods will ultimately churn out a productive group of nanotechnology knowledge workforce.

5.2.13 Infrastructural cost for setting up a state of the art R&D laboratory for nanotechnology

Many experts who were interviewed believed that, when it comes to nanotechnology, it is hard to generalize on the cost. The reason being is that, it largely depends on what type of area focus. In the case of nanoelectronics, the cost can be very high compared to pharmaceuticals, which can be much lesser. When anyone mentions nano, the basic equipment that comes to mind is the microscope. However, when it comes to the use of microscopes, the same is being used in all types of industries.

> ***AI:*** *For instance, the microscope commonly utilized by all areas is the Scanning Electron Microscope (SEM). A good field ignition scanning electron microscope can cost from RM3 – RM5 million for every SEM grouping. This is more expensive than a High Resolution Transmission Electron Microscope (HRTM). As for other microscopes, the Transmission Electron Microscope (TEM) may cost depending on which brand name between RM 6 to RM 10 million whereas a HRTM can cost to about RM 8 million or more.*

Nonetheless, there is the definite need for both SEM and clean rooms. In terms of total spending, management would require RM30 million at least to set up a nanotechnology R&D laboratory depending on the factors that contribute to the high cost of these microscopes. The reason being is that these machines are extremely complex and only a few people (companies) manufacture these complex machines; and on top of that, the expenses are high. It is considered a high end product. The capability is large and management will have to pay the price for that. Table 5.2 shows the average cost of microscopes utilized in the field of nanotechnology.

Table 5.2 Average Costs of Microscopes used in the field of Nanotechnology

MICROSCOPES	COST (RM)
Field Emission Scanning Electron Microscope	2,995,000
Scanning Electron Microscope (SEM)	1,465,450
Transmission Electron Microscope (TEM)	950,000
Atomic Force Microscope (AFM)	327,300

Source: High Impact Research (HIR) University of Malaya (UM), 2011

Some process equipment can cost up to a few million in total spending. The processing material however, is of a wider range. For nanotechnology, it could be cheap but at the same time be expensive. With a few hundreds or thousands, a researcher can undertake some form of processing. However, if you were to do high end processing, such as molecular beam epitaxy (method for depositing single crystals), then it could become very expensive. The good thing about nanotechnology is that the researcher can do both low cost/low end processing, as well as high cost processing. Nevertheless, for characterization, there will not be any compromise made but the management will need to pay the high cost.

> ***AU:*** *For instance, not every nano industry requires the use of a High Resolution Transmission Microscope (HRTM) because when it comes to a HRTM, it depends again on the application. If industries are strong into nanomaterial synthesis, they must make sure that they have all facilities to make nanomaterial synthesis possible. Nevertheless, in terms of characterization, if they don't have it, then the next possible thing they can*

undertake is outsourcing, and "what you have to cook, you do it in your own kitchen". This is knowledge propriety.

Certain nano related companies rely on this infrastructure from academia; which means, that the industry will go to the universities who have these equipment and they will send their samples for testing since it is convenient that way. This is because, in terms of the HRTM, for example, industry will not use it effusively 24/7 whereas the universities will have more use of it than the industry. Therefore, it is obvious that will not be worthwhile to have certain equipment "parked" in the industry. Hence, the use of nanotechnology infrastructure can be described as a mix and match kind of environment.

The cost of setting a sophisticated R&D lab in nanotechnology depends on how often the industry or the university will use that particular equipment. If it is not often, then it is much more viable to send industry samples to the collaborator. Equipment is expensive and requires skilful people. Unfortunately, when scientists would want to see things at the very small, it is never cheap. Biotechnology requires less infra or capital investment as opposed to nano. Furthermore, nano suffers from two (2) aspects: One, it requires more expensive capital investment; two, it requires the skill and the knowledge of the people. These two factors should be available in exodus. When it comes to maintaining microscopes, the cost is not high. The one, which absorbs the most money, for example, is the process equipment such as the chemical wafer deposition systems.

5.2.14 Requirement and amalgamation of multiple skills and its transferability into the field of nanotechnology R&D and commercialization

According to the standpoint of several experts who were interviewed, a number of nano related companies appoint leaders from the field of accounting and finance to steer-drive this technology. Based on a majority that is being observed, many hail from finance related backgrounds. Some of their backgrounds are completely out of scope from what is necessary for the field of nanotechnology. Nevertheless, Chieh Hang, et al (2009) decrees that managers in the past have progressively taken up more than just project charter roles while becoming assiduous for market development, new product development, intellectual property (IP) management and even basic technological innovation processes. This is predominantly true because at the end of the day, it is all about management. Largely, the success of the businesses run by companies in the field of nanotechnology relies on one: the management of resources especially financial resources. However, Chieh Hang, et al (2009) admits that there have been many graduates to date, who have occupied places in R&D and technology intensive industries in the public and private sectors. No matter how convincing Chieh Hang, et al (2009) may seem, it is very rare that you encounter proficiently technical people monopolizing the company boardrooms. Thursby, Fuller and Thursby (2009) have accentuated that innovation requires the expertise of (1) scientists or engineers engaged in invention and; (2) technology business experts who evaluate and develop business models for commercialization; and (3) attorneys involved in intellectual property protection.

> ***AX:*** *However, many fall through to cognize that nanotechnology is dissimilar from other technologies. In the field of nanotechnology, the technicality of the subject matter grows into a central issue since the market*

is not fully mature and above all, the awareness has not fully reached its "saturation point". The top management and the boardroom must fully apprehend what this technology is all about.

If the electronically inclined people were engaged and positioned, it could help provide valuable substance towards the product of focus if it is electronics related. At that juncture, they will be capable of interfacing between the different electronically driven products as to whether it is nano embedded or not.

AE: *They will be able to articulate. Another aspect that needs scrutiny is the amount of appreciation a person needs to have towards the product in focus. As long as the individual is adept in identifying and valuing the product in focus, they will be able to sell. One does not need to understand the technology expertise.*

However, what the individual needs to understand is the impact of the technology towards its target consumer market. Appreciation, in this context, refers to the full understanding of the impact of nanotechnology.

AQ: *If companies were to bring an intellect from the university who is proficient in the area of Physics and Chemistry, but who has never been exposed to the area of nanotechnology – the progression will still be swift. Nevertheless, if that person is not a scientist and if the company were to bring them into the organization to work on nano, then, they will not be* *capable of producing valuable results. Like a relay, they need to walk one-step more, and another step more. There will be a degree of overlapping, whereby some can cross, and some cannot cross*.

That is why more and more universities' professors should become affiliated with the companies, which conduct nanotechnology R&D. However, the point being made here is that it would be best to have the best of both worlds where by the decision makers of the company is punctiliously represented by the technology side as well as the business side. It is very rare to have all these qualities in one person or in one group. Furthermore, even if he or she is a technologist, but a technologist who lacks the coerce force to drive the technology, it will still be in vain. The other extreme will be when the technologist, may own the knowledge and competency of nanotechnology, but they may lack the realization of market penetration, since nanotechnologists also need to be realistic in terms of its future financial impact to the firm. Technologists need to recognize and understand that the market willingness must be there. Therefore, this is viewed as a challenge to technologists who must thrive to understand the industry mind-set.

> ***AC:*** *For instance, if the firm wants to go for market minus, same quality or better quality but same price; or to make something better with the same cost or to make the same product but at a lower cost in order for both public and industry to benefit, then the onus lies on the research community.*

What is required is a fusion of two very important elements: entrepreneurs and the technologists. If it is possible to combine to form a technopreneur, that would be exceptional. However, this is rare and not often found. For this to envision into a reality, the technologist will need to be more aware of the commercialization factors whereas the entrepreneur will need to educate themselves on the technical aspects of nanotechnology. However, it is improbable to turn a businessperson into a scientist. The phenomena should allow the scientist to be a scientist and allow the businessperson to be a businessperson. Each of them will need to make sure that any communication breakdown between sides is properly bridged and streamlined to increase its efficiency. In other words, every nano industry needs a strong champion with the right vision. This has not been achieved yet.

Chieh Hang (2009) stresses that companies' still recruit to fill functional roles as opposed to product champions or multidisciplinary roles. However, what nanotechnology needs is a technical architect to drive collaborations in the field of nanotechnology whereby he or she will strive to combine the roles of academic institutes and research institutes on a certain level of collaboration. Furthermore, there should be a consortium of technology.

> ***AI:*** *For example, a person who works in the pharmaceuticals can be utilized to drive the pharmaceutical area and a person who is working in the agriculture can be utilized to drive the agricultural area. From what is being currently observed, everyone seems to be doing their own small pockets of research but they are not converging.*

Therefore, what is required is a person or a single entity to merge them all together. An unimaginable amount of knowledge and expertise recites in the university. There is actually a bank of human capital stored within the solitude of the university; however, the research community should not be working in silo. The research community should be communicating more with the market or nanotechnology industry. There should be an amalgamation of roles placed in the field of nanotechnology. Furthermore, the management of nanotechnology is as imperative as the technical know-how's of this field. However, it would be a great asset, if the specific knowledge of the former were to be incorporated into the nanotechnology curriculum.

5.3 Summary

University researchers and students are undeniably the knowledge bearing assets required during the invention/discovery stage and prototyping/testing stage from R&D to the commercialization of nanotechnology. It is obvious that there is an absolute need for a skilled and educated workforce trained at an array of levels affiliated to this field of nanotechnology in order to congregate the projected demand in the future. Apart from the human capital and technological capability, aspects such as infrastructure and capital investment also come into play in the pursuit towards realizing a solid bridge between R&D and commercialization of nanotechnology. This chapter leads to Chapter 6, which incorporates the discussion, policy recommendations and conclusions for this thesis.

CHAPTER 6: Discussion, Policy Recommendations and Conclusion

6.1 Introduction

This chapter will discuss, provide policy recommendations and conclusions based on the main findings from this study.

6.2 Discussion

Institutional responses with respect to adhering to what would be an optimistic and affirmative time factor between R&D and commercialization of nanotechnology prototypes and products have been a far cry compared to what is putative and usually required in a R&D and commercialization research debate. It is not entirely the fault of policy makers considering the fact that field generalization of nanotechnology is difficult to envisage since nanotechnology is a scientific field that is heavily dispersed among various sectors of the economy, therefore the exaction of what would be a standard time frame between R&D, and commercialization is unconceivable now. However, this does not imply to suggest that there cannot be any policy recommendations to contract the lengthy time factor in order to assist in the swift transition of nanotechnology prototypes into products for commercial exploitation.

The process gap of internalization needs to shrink gradually to push product engineers to collaborate more with policy makers in order to actively generate real time evidence that constitutes real symptoms, which directly and indirectly contributes to the lengthy time factor between R&D and commercialization of nanotechnology prototypes and products. Problems and symptoms unsoldered can assist policy makers to entrust policies that can assist universities and firms in the R&D and commercialization of nanotechnology prototypes and products while carefully contemplating the economic, social, environmental, legal and ethical risks involved. Currently the differentiation of engineering and manufacturing processes encapsulated within each field defines the time factor and deters the possibility of achieving a standard time frame that would increase the transition speed of R&D into commercialization. Concept testing, product testing and market testing that serve as validation and rejection tools and which determines whether new prototyped competences are fit to infiltrate the market further augment the time factor. Uncertainties surface through these methodologies and therefore rather than looking at trimming down the time factor, it would be more prolific to trim down the uncertainties that occur within these processes, which ultimately will serve as a time contracting mechanism. Time inferences made by experts remain to be inconsistent and alarmingly irresolute but neither one has combated the possibility of attaining reasonable time dynamics of translating a nanotechnology prototype into a product within a stipulated period.

As how synthetic techniques engaged in the process of surmounting the diverse characteristics driven shapes into precision oriented and intricate homogenous contours can be a time refracting procedure, other engineering challenges have also negatively contributed towards the intensified time factor in the form of various nano related difficulties endured such as reproducibility of characteristics, unrealizable uniformity and regularity, production of large volumes, optimization and procedure complexity. No matter how much commercial or engineering knowhow, no matter how much market research is conducted on market maturity, market size, market share, and consumer profile, it ultimately boils down to how safe and innocuous is the product for consumer consumption and utilization.

Adding to this is the uncertainty of commercialization success that stems out from the mere fortification and certification of nanotechnology products given by the necessary authorities, which serves as a shield for consumer safety. From the milieu of consumer safety, it would be effective and practicable to have a cross-functional interaction of experts who have dealt with laboratory related experiments and who better understands the dangers behind the rate of exposure of nano particles and nano materials, piercing through various possible dimensions in order to be immune of hazardous issues pertaining potential nanotechnology products.

Adding on to this is the issue of IP whereby not all but a trivial percentage are translated into commercial output given the factors such as market environment, economic conditions and actual cost of production, which stifle the possibility of a prototype being converted into a viable consumer driven product. This phenomenon augments the greater requirement for universities to accommodate to market needs prior to any R&D escapade since the university's "third wing", which is academic entrepreneurship solicits commercialization of science; whereby any form of R&D conducted should be necessitated to expand for the purpose of commercial output. Hence, what is being connoted here is that the time factor between R&D and commercialization needs to be closely looked into so that it is in line and parallel with the market needs; that which goes into devising the nanotechnology product.

Due to the proliferation of a solid knowledge base that eventually leads to knowledge assimilation and accumulation triggered by an overwhelming demand of customer needs generated through constant feedback loops causes technological capabilities to evolve incrementally. Thus, the incremental evolvement of such technological capabilities is what brings about technological change. This technological change precipitates in parallel with time. The development of nanotechnology products revolves within this analogous mechanism whereby increased and "unresponsive" time expended on applied research will eventually cause technological capabilities that which depends solely on the potential of nano components experimented and derived from basic research, to become obsolescent and thereby, giving competitors a competitive advantage.

Initiatives on the other hand, that which come in the form of support and facilities are considered to be the external contrivance hailing from outside the technology environment used in the pursuit towards propelling a technology towards achieving its maximum potential. The complexity of nanotechnology, which involves the movement of atom and molecules and the aptitude and capacity required to manipulate the nano size does not in any way suggest that supplementary funding is necessitated for nanotechnology compared to other emerging technologies but does make a point in suggesting that support in generating a skilful human capital and workforce in the form of scientists and technopreneurs specializing in nanotechnology is significantly necessary. However, this formula alone will not guarantee in catalysing the field of nanotechnology in the effort towards transforming a nano prototype into a consumer driven product.

Insights from experts provide evidence that there should be a positive correlation between initiatives set forth and time taken for the transformation process if ever done successfully but there has not been any indicators to verify how successful these initiatives have been since their establishments. Outflow of funding is obvious but successful nano innovations are not yet vastly imminent because many countries' nano research keeps returning back to solving problems underpinning basic research after a continuous application and commercial downfall.

It is conclusive to state that in brief that the lengthened time factor can impede the research and commercialization of nanotechnology; and the level of productiveness of government initiatives can positively attribute but not necessarily solely catalyse the leap into successful nanotechnology commercialization. A change in structural dimensions and organizational architecture within the academia and industry environmental setting, a solid alliance and productive partnership between academia and industry, R&D legislative policies, and a meticulously planned and effective nanotechnology curriculum will add support towards catalysing this leap. These findings need to be considered for long term planning of research policy and in the implementation of future directions in nanotechnology.

More nano researchers should begin to make the giant leap from basic research into applied research in universities in order to stand in leverage with forefronts that are spearheading the nano revolution. For this phenomenon to take effect, it will require the augmentation in the number of skilled and knowledgeable workforce in nanotechnology especially in basic research, in order to champion the need to shift from basic research to the height and breadth of applied research. Endowing funds to commercialize nano-prototypes, appear to be a "jump the gun" approach to push nanotechnology development and should be regarded as too early at this juncture, considering that many projects in basic research is nowhere close to commercial realization. Therefore, there should be a certain amount of government focus into investigating why many projects funded for basic research are not mobilizing into the realms of applied research, where true potential of commercial realization closely lies. If initiatives carried out can be driven towards addressing the minor and major pitfalls and anomalies that obstruct the transition of nano prototypes into products within the university and industry arena – qualitatively and quantitatively, there is bound to be result worthy endeavours and implementations coming from university and industry through government assisted programs.

Based on the results and analysis, this thesis is able to make an academic validation that the diversified effect, which emanates from within the field of nanotechnology, can become immersed into the different tiers of education, lower than that of the undergraduate, Masters and PhD programs, in order to magnetize the younger generation towards the study of multidisciplinary science through the subject of nanotechnology. Ambitious it may sound but the validation made, forecasts the production of potential hybrids through the avid inculcation of "fused science" during the most adolescent years of students' learning. This will trigger the sporadic path of discerning and appreciating science through the multispectral angles of nanotechnology by way of diversified forms of patois and understanding, not just science but the non-science (management subjects) as well.

The true genesis of a U-I collaborative partnership originates from the exhaustive need to partake in the knowledge and technology transfer of pertinent assets available from each side of the treaty and that, which is profusely channelled asynchronously, will ultimately accomplish the core purpose of the treaty establishment. Nevertheless, the final product that eventually surfaces from the cross-inclination of both parties towards the projected outcome is often imminent but far reaching, due to the highly prioritized ambitions of individual entities. Nonetheless, the fulfilment of these priorities is the central sphere towards the sustainability of nanotechnology because they define the two opposite extremes, which are hard-core R&D and technopreneurship that ubiquitously determine the fate of this technology.

The repercussions that follow from the under settling intentions between university and academia can cement the possibility of any successful nano prototypes from envisioning. Hence, deep-down deliberations associated to the transitional blue print of prototypes into products and their corresponding spin off effects need to be capitulated by both entities in advance prior to the commencement of any R&D endeavour. From the findings, it is evident that the expected yield is to be the product of continuous re-engineering performed iteratively rather than "fast track" results achieved within a contracted period, which do not ensure innovation quality and thereby resulting in the planning of an unrealistic and representative time factor between research and commercialization by university and academia. Graduate student exchange coming from the academic platform into industry is not merely shaped to provide for the needs of the industry alone but also to be at the receiving end to "exploit the intangible profits" that arise from the use of highly equipped infrastructure and application personnel - the phenomenal relationship that can only occur with a high technology firm, which parallels to that of a graduate student exchange in terms of production engineers, designers and state of the art nanotechnology equipment.

The misapprehension that need to be set aside concerning all patents on the other hand is that, it's not necessarily 100% commercialized due to the non-existence and non-participatory role of the industry prior and during the conceptualization and development of the prototype, which results in the domino effect of unfeasible specifications and high ceiling cost, that are not viable in the real-time production world. Many prototypes are found sitting in the shelves because of this and patents are not readily absorbed and taken over by the industry. Nevertheless, this augury is reversible once the prototype is initially developed in accordance to the industrial market pre-requisites, which thwarts the domino effect of unfeasible specifications and unreasonable high ceiling production cost. This augury is also reversible once the protagonist roles of a university become that of a self-sufficient entity that can consist of their very own exclusive university spin off firm to run the commercialization process for the university.

Even though time-factor has never been given deliberate and continuous emphasis in research debates, considering that the consumption period between R&D and commercialization has often been predominantly contractual. Nevertheless, time-factor is pervasively making its mark as an impelling part of the R&D and commercialization landscape to the extent of offering a measurement of the level of rapidity or non-rapidness of processes that need to fulfil the expected timeline regardless of the level of attainment of desired outputs. Nonetheless, the tendency of the time factor to "withdraw itself from the expected timeline" is a result of the "out of the blue" intensity in the level of impasses that arise from the execution of these processes within the R&D and commercialization milieu.

This presage can be deleterious if there is a deficiency of core knowledge and skills of problem-solving nano related impediments that can be utilized to circumvent the possible externalities and internalities that surround these unpredictable deadlocks. The concept of nano safe is a form of a "branding" that comes with the territorial standards of assurance, which certifies whether a product is anodyne for consumer consumption. Considering that the term nano still remains just as a buzz word for now, the publics' "parboiled" knowledge of nanotechnology is derisory to be capable of discretely weighing the negative likelihood that might ascend from the consumption of nano- embedded products and how it will impact their daily lives; resulting in ambiguous information being misconstrued. Nevertheless, whether the public is sentient or not, this still leaves the product safety regulators fully liable for any anomalies that arise from its product usage and to consequently address safety and awareness issues pertaining nanotechnology through a more serious approach. Therefore, with the aim of strengthening nanotechnology safety and preventive measures, U-I collaborations will need to impose its fullest obligation in response to the percentage (%) of nano components and materials embedded in a product deemed as a nanotechnology product and to the level of exposure it interposes itself to the consumer, as an outreach towards attaining nanotechnology sustainability.

This frequencies the need for the selection of an impeccable medley of trouble shooting engineers by key stakeholders of the U-I collaboration who will be able to precipitate the process of continual re-engineering of nanotechnology products and thus contribute towards the long-term sustainability of this technology. The scenario in which heaves both entities into the non – communal and contradictory directions, which navigates towards the expanse of patenting and the other into the expanse of publishing can be incentivized to demonstrate the flexibility in each other's priorities. Apart from these nuances, what can be ascertained is that the extent of which can propel academia towards the solvation of confounded hitches within the industry's quandary can also complement the extent of which can propel the industry to unearth the capabilities of academia; resulting in academia to shift from the safer inner boundaries of mere academic pursuit into the outer boundaries of untested yet prolific nanotechnology emerging postulations. When the extent of these thrusts become submerged within the U-I collaborative partnership, it can ensure the sustainability of nanotechnology.

The deficiency of shrewd business acumen entrenched within the academic capacity does not entirely stagger its position within the collaborative partnership, which moves in pursuit towards the commercialization of a nano embedded product. In fact, academia, which is deeply entrenched within the realm of basic research, is indispensable in the forefront towards maximizing the potential of an emerging nano product because the unpredictable yet dilemmatic intensity of predicaments that arise at the stage of application research is bound for "continuous backward re-engineering" in order to "smoothen up the rough ends".

Entwining the ideals sheathed within the protectorates of academia and industry reinforces the principles needed to attain the diversified form of hybrid required for the sustainability of nanotechnology. This means, apart from the educational spinoff effect that emanates in the form of knowledge and technology transfer, that in which moves asynchronously back and forth from academia to industry and vice versa, is the training of low to high skilled production and manufacturing workforce based on training modules that can be conjointly formulated by both knowledge based and industrial based frontiers, in order to mutually educate an assortment of nanotechnology workers from both sides of the end streams.

Henceforth, the essence unfolded through this thesis is to justify that U-I collaborative partnerships can ensure the sustainability of nanotechnology if only the channels through which both entities transport their individual capacities are executed through approaches discussed in this thesis. This thesis also makes a standpoint that a U-I collaborative partnership can be regarded as one of the influencing factors that warrants the sustainability of nanotechnology.

The clearest path towards addressing something as wide and comprehensive as nanotechnology is by navigating through its connective associations with the fundamental relative sciences in order to make visible of the various combination of sciences being synergized and distinctly defined by nano. From the coverage of mainstream subjects in the undergraduate program with the offering of a minor in nanotechnology will not able to guarantee a pure concentration in a nanotechnology area during the Master's program since it is highly dependent on which mainstream subject during the undergraduate program is likely of interest to the learner for further advancement in that area.

The lack of proficiency in other science disciplines leading to the study of nanotechnology will not prevent the learner who is proficient in a single area to pursue nanotechnology and learners need not require a thorough and comprehensive knowledge of nanotechnology from various sciences in order to make a contribution in this field. However, proficiency in a single area of science will create inflexibility in the movement towards expanding in the field of nanotechnology. In terms of setting up a nanotechnology curriculum during the undergraduate program, this thesis does not conclude, to suggest that a nanotechnology undergraduate program should ever come to exist, but to suggest that the focus of the undergraduate nanotechnology program should be to entrench a strong nanotechnology foundation, which will be difficult to conceive, even though not a specialization, rather than focusing on a too broad a programme, whereby students end up knowing little about every science discipline but not enough in any field to make a significant contribution. The completion of one's Master's education in a single field of science will provide the ability to adapt to other sciences and transcend into the pure concentration of nanotechnology. Therefore, a standalone nanotechnology program, which amalgamates the various sciences, has more prospects of being developed as a doctorate programme rather than the undergraduate or Master's programme. The setting up of a standalone nanotechnology programme has the potential capability of producing a set of hybrid expertise required for the R&D and commercialization of nanotechnology. In terms of communicating across the various sciences, interpretation, understanding and innovating will be a challenge if one is only proficient in a single area of science and not able to adapt to various scientific interpretations. This means that interdisciplinary and multidisciplinary interpretations will not be able to communicatively synchronize to reach a similar frequency.

Postgraduate training and experience during the Master's and doctorate programme is paramount in the utilization of laboratory microscopes as high levels of training is required in interpreting the results attained through the use of microscopes. High level of maintenance is required for microscopes such as the Transmission Electron Microscope (TEM) and technicians only perform low-level maintenances and will not be able to perform higher maintenances by themselves, and therefore, leaving the experts who built the machines to carry out the maintenances. Therefore, in the context of utilizing a microscope and maintaining one, the expertise of the knowledge worker is mostly required than that of a technical worker. Cost of nanotechnology equipment cannot be generalized as it depends on the area of focus and on how often that equipment will be used. It is also dependent on the type of microscopes required, the specification and functionality of each microscope, processing material, processing technique, the amount of utilization and level of skill required to use the high end/low end microscopes. The level of utilization of a microscope can reduce the acquirement of higher cost equipment for a lesser cost alternative since the acquirement of high cost equipment is for the purpose of maximum utilization for nanotechnology experimentations.

A sound management knowledge of the essentialities and priorities of nanotechnology experimentations will be able to make pivotal cost balancing matrixes without comprising the quality of laboratory methodologies. In the field of nanotechnology, technicality of the subject matter becomes a central issue, since the market is not fully mature and awareness of this technology has not immersed into all strata of society, while creating the need for management to be equipped with a level of technology expertise, rather than solely relying on interpretation of experts on the impact of the technology towards its target consumer market.

With reference to the underlying themes, a set of recommendations have been meticulously described for the main aim of progressing and augmenting the development of nanotechnology to a higher level in terms of R&D policy, incentives, initiatives, endowments, safety, awareness, linkages, infrastructure, education, entrepreneurship and availability of statistics.

6.3 Recommendation for Future Policy Directions

The following are recommendations to enhance the development of nanotechnology in terms of R&D and commercialization:

i. R&D policy concerning nanotechnology must take into consideration the multiplicity and diversity of economic sectors so that standards and procedures can be developed and moulded to suit each sector appropriately. The R&D policy will also be dissimilar from county to country's environmental setting. Therefore, it is unlikely that one country's R&D policy will fit the needs of our country's nanotechnology R&D agenda. There are R&D policies of countries, which have been successful in contributing significant R&D output, which our country can indoctrinate in terms of improving its effectiveness and efficiencies with the foremost mission of positively bringing out not just inventions but innovations that will be successful in the marketplace. Meaning to say, R&D policy need not just spell out the needs of research and development in a particular area but also pronounce clearly and explicitly that its ultimate agenda is to steer its way towards the commercialization of a R&D prototype or invention. With that in mind, the nanotechnology R&D policies should be meticulously planned with various parties involved (better still if every economy sector is represented) without allowing any room for ambiguities that can possibly cause mediocrities concerning nanotechnology prototypes, products and successful innovations.

ii. The nanotechnology R&D policy should take into careful contemplation the time factor involved between research and commercialization with special deliberation on the requirement for clinical testing, robustness of the technology, compatibility and other post - development technical procedures that make nanotechnology a cut above the other technologies in terms of complexity. It should put in place the necessity to adhere towards a certain time limit to produce a product from the time of its basic research until applied research right up to off shooting a fully-fledged product in order to prevent resources provided by the government from becoming unworthy of its cause. This action will also impact on the positive utilization of government resources.

iii. The nanotechnology R&D policy needs to manifest a clause that if ever universities are in any way paralyzed by way of not being able to provide a prototype that suit the needs of the market, then they will be indoctrinated to amalgamate or bring their scientific ideas to the attention of a firm (prior development) who will be able to furnish them with the business perspectives and current market trend so as to prevent these prototypes or inventions from sitting in the shelf later. In other words, these firms will guide these universities (not in terms of scientific expertise) but with the current market needs prior development of a prototype. This way, the cost of making the product can be advocated earlier on and a straightforward financial rundown can be envisioned prior development. This too will impact on the positive utilization of government resources endowed on universities.

iv. In order to bring out an invention or a product on time for market release, the government should be able to provide incentives or assistances from the perspective of reducing the time factor. These incentives and assistances should come in the form of assigning product engineers and design specialist to work closer with scientists in the labs in the course of their research and development. Either these product engineers or design specialist can be the direct product of a university podium itself or the product of years of firm experience. However, the selection of these personnel should be based on their sharp expertise on nanotechnology. Scientists can request them for their projects with the condition that these research projects will be completed within a stipulated period.

v. Since the primary reason why governments provide endowments to universities to perform research is for them to be innovatively productive – meaning to say, bring out innovations that will be successful in the market place. This is the era of commercialization. Except for the medical research of a particular drug to cure cancer and AIDS which takes numerous years, these government endowments are not for the purpose of allowing scientists to remain stationary at the phase of nanotechnology basic research but to progress to the stages of applied research. If ever this being the case, then the government R&D council should hold a monitoring committee to enquire the solid reasons for delaying applied research considering that a great amount endowments have been supplied to research universities to bring out obvious applications. This would help construct a precipice between research in the university and commercialization in our country. More nano researchers should begin to make the giant leap from basic research into applied research in universities in order to stand in leverage with forefronts that are spearheading the nano revolution. For this phenomenon to take effect, it will require the augmentation in the number of skilled and knowledgeable workforce in nanotechnology especially in basic research, in order to champion the need to shift from basic research to the height and breadth of applied research. Endowing funds to commercialize nano-prototypes, appear to be a "jump the gun" approach to push nanotechnology development and should be regarded as too early at this juncture, considering that many projects in basic research is nowhere close to commercial realization. Therefore, there should be a certain amount of government focus into investigating why many projects funded for basic research are not mobilizing into the realms of applied research, where true potential of commercial realization closely lies. If initiatives carried out can be driven towards addressing the minor and major pitfalls and anomalies that obstruct the transition of nano prototypes into products within the university and industry arena – qualitatively and quantitatively, there is bound to be result worthy endeavours' and implementations coming from university and industry through government assisted programs.

vi. An independent agency (separate entity) needs to be set up to look into the safety of nanotechnology inventions prior to mass production or market release. NND cannot absorb all these responsibilities. Exploring and probing into the safety of nanotechnology should be a sole and designated role or portfolio authorized to an independent agency. Since it will take a while for the public to become aware of the issues surrounding nanotechnology, the government should take full responsibility in determining whether or not these products are safe and healthy for public usage. At the outset or the beginning of its initiation, it would be advisable to seek the advice of other countries' experts who have experiential knowledge of its disastrous characteristics and behaviours so as to prevent the anomalies circulating nanotechnology from out bursting within our country's environment. These experts who will form the agency need to come from a multidisciplinary array of know how's entailing biology, chemistry, physics and technology management to better understand the incongruities and discrepancies of this technology such as exploring how the technical and precision intricacies that influence the nano chemical activity can be better managed. The agency will be given the sole authority for certifying nano products. However, this agency will be positioned under the technological wing of a higher ministry who will be able to monitor its activities.

vii. Awareness needs to be spread to the society as a whole on what nanotechnology is all about. The aspect of safety can only be thoroughly said to have reached a saturation point if only there is at least a certain amount of understanding absorbed by the many different types of people who form the society at large. They have to be rationally warned of the side effects and dangers of unapproved and uncertified nanotechnology products or told to realize its gains in order to fully embrace its potential. Therefore, the government needs to start organizing two way interactive talks on the subject of nanotechnology and its role in society so that it is not entirely misconstrued. The talks should be structured in a way to be able to provide a surface view of the subject in lay man's terms. Schools, organizations, non research universities and shopping complexes are the best platforms to conduct this initiative but it has to be done in a continuous manner because people tend to forget in the long term. The next best platform would be the media – channels that are widely viewed by the people. Another appropriate method would be to construct unsophisticated yet informative booklet or CDs, which will be easy to comprehend and understand - on the subject of nanotechnology and provide them to schools and non-research universities. This successful turnout of this agenda could possibly become a catalyst towards increasing the demand and supply of nanotechnology products in the future.

viii. There should be a fixed criterion and requirement that a product needs to comply with in order to be categorized as a nano product. There should be an explicitly stated specification of what percentage (%) of nano component needs to be embedded in order to be declared as a nano product. Utilizers need to be made aware what kind of level of exposure and level of detriment it interposes itself to the utilizer. This should form part of the safety standards to ensure manufacturers do not misuse the "nano" label with non-nano products. Some products are labelled nano but not necessarily contain any nano materials or nano particles. There is no restriction or any provisions for this at the moment. Therefore, products that claim to be embedding nano materials and which were created to boost the impact of the solution for the purpose intended for, need to be thoroughly examined by the agency. If found that there is no nano material or particle contained in the product, the agency should issue a marker (sticker tag) on the product indicating this for the awareness of the people or even stating its possible side effects in the case of prolonged use.

ix. Government initiatives and its missions with regards to nanotechnology need to be in coordination with one another. Except for grants being issued to universities by the ministries, currently there are no obvious linkages between the two. Research institutes (based in universities) are conducting many research activities but they are not being scrutinized or monitored to find out how productive are these research activities. Therefore, there should be a comprehensive plan crafted by the endowment agency/ministry to track the progress of these research funded activities that includes making physical visits to scientists' labs/workshop where the research is being conducted; and grants to be segmented conditionally based on various phases of research outputs (and not be made in lump sum). This will augment the standards of nanotechnology research productivity in our country.

x. Since many universities are said to be lacking very crucial infrastructure required to conduct nano research, these pertinent infrastructure for nanotechnology should be purchased and given to universities directly by the government instead of assigning the universities the responsibility to make the purchase themselves; and also restructure the high allocation given to universities. Meaning to say, the allocation can be restructured in a way that it will consider only the cost of materials, human capital (excluding equipment) and cost of maintenance. Being very exorbitantly costly, the universities have complained of not having enough from their allocation to set aside for paraphernalia. Therefore, this dilemma can be resolved if the endowing party provides the university in the form of paraphernalia instead of monetary. Once this matter is dealt with, then the government can proceed to examine to what extent has this initiative made a difference to the standard of nanotechnology research productivity.

xi. University PhD and MSc students coming from science backgrounds should be instructed to study the maintenance manual of the necessary equipment so that in lieu of suppliers, graduates will able to conduct the maintenance on the equipment as part of their practical training or hands on training experience. This will ensure that these postgraduates will understand first hand of the ins and outs of the functionalities of microscopy equipment used for nanotechnology.

xii. Nanotechnology equipment that far exceeds the minimum cost threshold of government estimated expenditure can be placed in a centralized unit of each university. This can prevent the hassle and time depletion for one university from visiting another university to use a specific equipment. Instead of purchasing equipment for each science faculty/department, all science faculties according to time allocations can utilize one unit. This aspect is taking in consideration the verity that these equipment are not necessarily used 24/7.

xiii. Above paraphernalia, it is the scientists, researchers, technopreneurs and entrepreneurs who are greatly required in the field of nanotechnology. In order for many transformations from prototype to product to flourish, the number of hours and number of specific expertise need to be amplified. The number of researchers in nanotechnology in Malaysia cannot be measured without properly instilling criteria levels to define who can be referred to as researchers in nanotechnology. This should be the role of a census survey.

xiv. Encourage large local companies (e.g. oil and gas) to prioritize nanotechnology research as part of their policy and provide opportunities and grants to PhD research students to work with them in nanotechnology. In this sense, professors from our country's premier universities can become affiliated with these companies on a contract basis. On top of this, these large companies can endow universities with research grants to conduct further research in nanotechnology.

xv. Due to the unavailability of proper coding systems to classify firms according to specific nanotechnology related activity and to make known to universities as to whether or not they are purely nanotechnology based, disables the ability to properly target the right firms to establish partnerships. The Registrar of Companies need to annually assess the number of companies involved in nanotechnology in this country and find out how many are legitimately registered nanotechnology companies and revamp the specification in distinguishing, which firm is eligible to be categorized as a nanotechnology firm and triggering the requirement to constantly review firm activity to avoid legal penalties. Physical annual visits need to take place to see for themselves whether these companies really exist.

xvi. The Department of Statistics (DOS) and the Ministry of Science, Technology and Innovation need to measure the number of scientists/engineers involved in nanotechnology locally and globally, number of student enrolments and number of degrees/majors conferred in the area of nanotechnology in universities (if any). Many universities claim that they have many graduates specializing in the field of nanotechnology; however there is no evidence to support this claim. Therefore, it would benefit the science community if these two (2) organizations were to carry out out a census to measure these statistics even if the number is small; so that the science community is aware. If the cost of carrying out census of this sort is excessive, then the government needs to also consider this cost in their annual budget allocated for nanotechnology.

xvii. In addition to this, apart from DOS and MOSTI providing information on spending by each country on nanotechnology, it will be more beneficial if governmental statistical surveys and census reports begin tracking figures on 'how' each country involved in nanotechnology activity' spends the total amount of governmental spending on nanotechnology.

xviii. Government should provide tax exemptions for SMEs that conduct R&D in nanotechnology. These tax exemptions should be offered for at least 10 years (not 5 years which is the minimum number given to SMEs conducting any type of R&D) since it takes a lot of high investment to venture into nanotechnology and returns could only be seen in a long term basis. However, in this case, the Registrar of Companies needs to collaborate with organizations like MIDA to monitor the progress and existence of these companies. It is of no use giving out tax exemptions to firms that claim to be conducting R&D in paper but do not conduct any type of R&D in reality.

xix. From the perspective of funding, financial aid by public and private to start-ups to be classified into different stratums; one of them being nanotechnology start-ups. Owing the fact that financial institutions have provided many forms of fiscal aid to SMEs during the past decade; it's time for these institutions to further prioritize their SME aid into different stratums. Meaning to say, focus should be directed towards the SMEs/start-ups involved in nanotechnology.

xx. The main reason for SMEs for not venturing into the field of nanotechnology is because high technology can be risky business. Therefore, the Ministry of Finance should be able to provide some kind of incentive such as "*guarantor-ship*" or a helping hand if in case these companies fail.

xxi. The Ministry of Education together with the higher tertiary universities should begin crafting ways to develop a creative curriculum for kindergarten students to study not the the basic but the "pre – basic" aspects of nanotechnology. At present, it will not be seen as useful but in the near future, it will serve worthy in the long run. When pre-school students are able to play video games and computer games - that which was unimaginable 50 years ago, is comprehensible today. The integration of nanotechnology in the pre – school curriculum will be able to help boost their mind's eye of the movement of tiny particles (referring to atoms and molecules) picturesquely and serve as "pre – foundation" or preparation to boldly take on science subjects when taught in schools.

xxii. The subject of nanotechnology should be incorporated into the undergraduate curriculum particularly in Management, Information Technology, Social Sciences degrees and also in the MBA curriculum. It should be provided as a core subject or offered to students as a minor/major option.

xxiii. The missions of each individual member of an industry - academia partnership should be made clear right from the beginning. The different directions headed by both industry and academia should be able to ultimately reach a common goal. Even though research publications still measure up as a standard benchmark used in university rankings and there are very few scholars cum patentees in our country; over the years, academia has also recognized the importance of patenting. Nevertheless, it is the industry that is not willing to have a positive outlook towards the importance of academic publications. Industries in Malaysia should be made aware that many inventions or successful innovations have been the result of conversions from paper to prototype. Industries pride themselves with their own 'publications' but it is the university academic research publications that are certified as *qualified*. If ever industry is hesitant in disclosing data for the purpose of university publications, then this is where the relevant parties should identify their needs and together craft a constructive and productive work plan to address this issue. As it is, there are so many partnerships, but no evident innovations as proof of output.

6.4 Suggestions for Further Study

The standard definition of what a "nanotechnology firm" constitutes is still not available. The fact that numerous statistical measures have been undertaken in measuring the number of firms existing worldwide; the figures remain incomprehensive and incomplete with the absence of this key definition. In the past decade, from what has been mentioned earlier, individual researchers and research based governmental organizations have provided contradictory and inconsistent statistics on the number of nanotechnology firms that exist today across the globe. This could be due to the fact that each researcher prescribes their own definition of what a "nanotechnology firm/company" really means. Be that as it may, none of these researchers have recorded their definitions in their reports and publications as to how they define a "nanotechnology firm/company" based from their own standpoint and assumptions.

Hence, until today, there is neither a standard definition nor characterization for a "nanotechnology firm/company". Therefore, this discussion leads to the following questions: *Does a "nanotechnology firm" need to actually manufacture nanotechnology products? Or do these companies also comprise of regional distributors for local and foreign companies that manufacture these products? Or do these companies need to have invested on a R&D lab for nanotechnology? Have they specifically been created to develop nanotechnology? Or are they mere subsidiaries of large companies or industry groups?*

Prior to measuring the number of nanotechnology firms by sector or by location/country, it is imperative to specify the exact and clear definition of a "nanotechnology company/firm" by government regulators to ensure consistent measurement of nanotechnology data in the future. Once these questions have been dealt upon, then a clear and comprehensible definition will be attained of what a nanotechnology company really is. Flanking this issue is another aspect, which is: *What constitutes a "nano product"?, what requirements or criteria does the product need to comply in order to be categorized as a nano product?, what percentage (%) of nano component needs to be embedded in a product to be a declared a nano product? For instance, if a product contains only 0.0009% of a nano component embedded inside; can it be also referred to as a nano product?*

Therefore, the question arises as to *"Which products can be justified as nano products? and "how do you designate a product or process as nano?"* In order to solve this dilemma, a comprehensive definition of what 'nano products' really means should be realized and with the intention that, in the future, data measured by funded research groups, independent bodies or governmental organizations will be consistent and in line with the prescribed definition. Thus, these definitions have been missing from intellectual debate in the past and present. It is pointless for statistical organizations to conduct studies on measuring nano firms and nano products available worldwide without a thorough and comprehensive definition of the two.

6.5 Conclusion

There is an absolute need for scholarly and industrial dialogues to immaculate the ambiguities surrounding the solvation of time factor circularities, which are capable of incapacitating the R&D planning process from successful execution. Despite the fact, that the standard time frame is not easily predictable at the earlier stages of R&D, however, certain past measurements need to be enacted en-route towards forecasting and identifying gridlocks that might incur along the R&D journey and that which can disrupt the estimated time factor. Still, considering that gridlocks incurred vary from prototype development to another, it would be challenging to make a valid estimation beforehand. Therefore, it would be worthwhile to invest a certain degree of government expenditure in producing graduates who specializes on problem solving methodologies on top of their subject matter expertise. Nevertheless, the integration of knowledge embedded problem-solving methodologies into the curriculum can only be realized via the use of real time engineering and scientific case studies to stimulate the cognition and resourcefulness of graduates attempting to discover creative ways to apply theory into practice. Nonetheless, the question arises as to, how many case studies involving problem-solving methodologies stretching from multiple R&D processes can be discoursed throughout the study considering that no two (2) dilemmas are the same. The perennial march towards cognizing a number of problem solving methodologies inculcated through a series of real time engineering and scientific case studies will have the capacity to catapult the leap into solving gridlocks that are more difficult to handle and therefore producing more and more problem solving intellects for the R&D community. The long-term effect of this recommendation will be able to counteract the lengthy time factor predicament in order to assist in the swift transition of nanotechnology prototypes into products for commercial exploitation.

The nonchalant bridging between policy makers and R&D specialists inhibits knowledge transaction from inter-looping with one another and thus creating an under synchronized atmosphere between two parties. Therefore, policymakers in the course of drafting out policies for R&D cannot tactfully address current dilemmas experienced during the R&D processes and thus are incapable of creating specific policies to aid in the commercialization of R&D prototypes. The diversity of multifarious processes that defines the uniqueness of each individual prototype development stretching across a vast array of economic sectors, in reality prevails the existence of a one size fits all solution. Testing procedures, which are paramount towards ensuring product safety is inexorable and cannot be wiped out from the PERT chart. They remain to exist as core processes. What all-unique prototype developments share in common is that they are not immune to uncertainties and therefore, this phenomenon manifests reasonable grounds for achieving an effective time contracting mechanism by attempting to plunge uncertainties to the core minimum. Time contracting mechanisms can also diminish the qualms by investors and venture capitalists that have second thoughts in seeding a project from its premature level and assure them that the outcome will ultimately meet the needs of their principal purpose for investment. Reproducibility of characteristics, unrealizable uniformity and regularity, production of large volumes, optimization and procedure complexity are the insurmountable concerns that surround the impending result of the final developmental outcome. Despite the immense and past experiential knowledge contained within the vast knowledge bank of human capital, there are always newer and unknown boundaries ready for exploration, to ratify the fitness competency of each prototype development prior to market release, especially in the case of nanotechnology. The perennial emphases on the safety of nanotechnology products for market consumption need to be continuously fortified, because the technology, which bears the name of limitless potential, also bears the name of limitless destruction, if not amply tested and diagnosed according to established safety standards. Nevertheless, it would be pertinent for governments who are making strides on boundless nanotechnology efforts within their own countries to establish safety standards specifically for nanotechnology products. In a way, the establishment of safety standards specifically for nanotechnology would be a boost to the nanotechnology industry rather than a prolonged commercial encumbrance, because it would be safer to publicly, authenticate a product as innocuous for market consumption by more than one testing laboratory or institution prior commercial release rather than it being pulled off from the shelves after.

Apart from safety standards, is the aspect of patents, which are being profusely produced but lacking the overwhelming response from apposite companies who do not seem to be intent in converting them into commercial reality. From the bird eye view of academia, patents are flourishing; however, through a bird's eye view of the industry, patents are not productive due to an occurrence of a U-I partnership syndrome, which can be referred to as "development unconformity" to the needs of the market. Therefore, this constant occurrence, which prohibits dynamic transformations, triggers the greater need for academic entrepreneurship. Incremental trajectories leading to more efficient technological competencies are the threshold of any competitor driven product development. Fast forwarding processes by evolving and reforming from past blunders of long term radical developments is an indication that time contracting mechanisms can be triumphant in the short term. It is a known verity that the potential aim of initiatives, is to elevate the likelihood of attaining any significant output of any size to the level of significant outcome. Nonetheless, billions of dollars is being spent each year by governments internationally to elevate this likelihood, but there has not been any initiative to counter ensure whether the level of significant government expenditure is parallel to that of the level of significant output. Therefore, the need to augment the amount of expenditure towards attaining significant output within nanotechnology efforts becomes of less importance compared to the need for prioritizing prevalent allocations towards producing more talented and knowledgeable workforce in highly prioritized areas of this technology. To dwell deeper, this skilful workforce should be consisting of postgraduates specializing on problem solving methodologies on top of their subject matter expertise and "tailored to fit" for the industrial research community. Nevertheless, the foreseeable augury of this prioritization reminiscent promising outcomes in the field of nanotechnology but necessitates the need to backward call industrial scientists to "ripen" the existing curriculum to apropos according to the needs of the market. The predilection funnelling towards encroachment in curriculum specialization can precipitously prepare individuals in discovering creative ways to minimize time between research and commercialization in the field of nanotechnology.

Thus, it can be coherently reasoned that nanotechnology is discernibly a pioneering and complex technology and to be regarded as an archetypal of the more advanced type of knowledge work expected of the workers in the 21^{st} century. This is due to its multidisciplinary nature and the understanding of the amalgamation of sciences, which when merged to bring out a new technology such as nanotechnology, will make it tough to grasp and conceive due to its intricacies. Students stringing from an assortment of science disciplines will have an opportunity of surviving nanotechnology as the progression will be at full tilt; however, it would be challenging for management and business oriented people to apprehend and cherish the impact of this technology.

For this to ensue, it is essentially pertinent for technology-management education to integrate the fusion of various scientific disciplines to cater for the needs of nanotechnologists and to yield a hybrid formation of both technologists and entrepreneurs. It also should be emphasized here that the predicaments associated to nanotechnology education can inform our thinking about education that prepares knowledge workers for the 21st century in terms of creativity and innovativeness. On top of all this, university researchers and students are undeniably the knowledge bearing assets required during the invention/discovery stage and prototyping/testing stage within the R&D and commercialization processes of nanotechnology. There is a positive need for a skilled and educated workforce trained at an array of levels affiliated to this field of nanotechnology in order to congregate the projected demand in the future.

Apart from human capital and technological capability, infrastructure and capital investment also come into play in pursuit towards contributing to the production of knowledge workers from university right up to job vista. It has been evidently proved that nanotechnology can be viewed as a fundamentally interesting case of the growing importance of interdisciplinary/multidisciplinary education for work in the 21st century; as well as a quandary more than it is a likely frustration for companies who look to educational institutions to prepare future employees. It must be emphasized that this thesis does not in any way imply of narrowly "scientizing or modernizing" the entire education system by embedding the concept of nanotechnology but provides evidence that justifies the importance of entrenching the education of nanotechnology as a fraction of the existing science and management education, which we have today. In view of the growing importance of R&D and commercialization of nanotechnology, it is pertinent to create better-prepared knowledge workers who are not subservient but erudite and conversant of the instrumental scientific and commercialization imperatives. The technology-management knowledge of these imperatives needs to be meticulously “curriculumed” into the nanotechnology education, that which should be made accessible within all stages of the education system whether it is in the secondary school system or the university undergraduate or graduate programs.

Scientific contributions have produced significant impact and are incessantly bringing new breakthrough inventions to the public interest; and even though potential uses of nanotechnology are immensely available, on the contrary, potential destructions are yet to be experimented, diagnosed, certified and brought forth to the people’s awareness. This paper, however, does not touch upon the elements of environmental, legal, ethical and precautionary principles of nanotechnology; for which these elements branches out from a new study known as nano-ethics. Recently, the Project on Emerging Nanotechnologies (PEN)’s Nanotechnology Consumer Product Inventory has found that the number of manufacturer-identified nanotechnology-enabled consumer products, which have entered the marketplace to date has increased to over 1,300. That is almost double than it was in 2008.

Thus, what is being elucidated here is that, the fractional embodiment of nanotechnology education into the technology education system for engineers and managers do not have to solely rely on the concerns of what the scientists, regulators and citizens have for the potential destruction of nanotechnology in terms of health and environmental damage. The careful reflection of what constitutes to the education of nanotechnology will categorically integrate this profound information. The closest it can come to would be the assimilation of the subject of “Nano Ethics” into the technology management subject through the nanotechnology curriculum, which would be an evolutionary sign in terms of addressing the concerns of our fellow scientists, regulators and citizens in terms of possible health and environmental damage.

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SUPPLEMENTARIES

LIST OF PEER REVIEWED PUBLICATIONS AND PAPERS PRESENTED

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