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Developing a Model for Nanotechnology Knowledge Co-creation

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Abstract: Nanotechnology conforms to a pattern of science based innovation, where an important revolution in analytical instruments (such as STM, AFM), preceding discoveries and subsequent technological advancement stimulated the exploration of nanoscale structures and the developments of nanoscale technologies. Nanotech has no clearly defined boundaries since nanotech stands for its multi-disciplinary characteristics due to its nano dimension and thus affects various technological domains and scientific disciplines. Therefore, it has been of importance to explore how nanotech knowledge has been created through technology sectors and disciplines. This paper shows the pattern of nano-knowledge creation and develops a model for nano-knowledge co-creation. The research could be particularly useful for learning the way of nano-knowledge creation in the early stage of its commercialization and could help in forming technology strategies and science & technology policies as well as for scientists and researchers of scientific disciplines or different technology domains in the global community.

Keywords: nano-knowledge co-creation model, nanotechnology domains, scientific disciplines

INTRODUCTION

In the nearly half a century since Nobel Prize winner Richard Feynman advocated widespread nanoscale research by delivering his famous speech "There's plenty of room at the bottom" in 1959, through which nanotechnology concept (concerns of manipulation of nanometer-length atoms, molecules, and supramolecular structures in order to generate larger structures with superior features) first captured the world's attention. Nanotechnology comprises one of the fastest-growing research and development areas in the world (NSTC 2006). Like many future areas of scientific and technological exploration, nanotechnology exist on the borders between disciplines including physics, chemistry, materials science, biology, medicine, ICT, and engineering. Nanotechnology has evolved into a revolutionary area of technology-based research, opening the door to precise engineering on the atomic and molecular scale and thus affecting different technology sectors everything from healthcare to the environment (Roco 2007). It can be predicted that in the coming era, nanotechnology will emerge as a strategic branch of science and engineering (Islam and Miyazaki 2006) , fundamentally restructuring technologies used for manufacturing, medicine, defense, energy production, environmental management, transportation, communication, computation, as well as education. This technology of small scale already plays an important role in fusing scientific disciplines (Islam and Miyazaki 2007), with having the ability to fundamentally change the way almost everything is designed and manufactured, from automobile tires and tennis racquets to air purifiers and life-saving vaccines[1].

RESEARCH PROBLEM AND METHOD

The main objective of this research is to explore the pattern of nano-knowledge creation through technology domains as well as scientific disciplines and how this pattern has changed over periods. The research then proposes a model for nano-knowledge co-creation. Nevertheless, the question arises here how we analyze the process of nano-knowledge co-creation. Concerning this issue, we approach in several ways, such as i) searching at the whole nanoscientific output retrieved from COMPENDEX database and finding out how nano-knowledge has created through nanotech domains; ii) searching for ISI general disciplines' journals output related to nanotech research over periods; iii) searching their reference citations and then classifying the cited references into disciplines. The analysis is based on a combination of quantitative (using SCI database over the period of 1995-2005 at a 5 year interval by selecting top rated and most common 25 journals of each disciplines classified by ISI) and qualitative (conducting interviews with academic scientists and researchers from university and public research institutes in Europe and Japan) method within the framework of systems of innovation (Lundvall 1992, Malerba 2002, Nelson 1993).

MODEL OF NANO-KNOWLEDGE CREATION THROUGH TECHNOLOGY DOMAINS

Earlier we have characterized nanotechnology domains using Engineering Index (EI), defined by Elsevier COMPENDEX to assign specific codes to every article in the database[2]. We also analyzed the

[1] [For example, nanoparticles are used in automobiles for filler in car tyres, nanoporous filters to minimize the emission of particles on the nanometer scale, catalytic nanoparticles as a fuel additive; carbon nanotubes are used in tennis racquets, field emission display (FED), transistors, fuel cells and high-performance battery]

[2] [Earlier we have characterized four nanotechnology domains such as nanomaterials, nanoelectronics, nanomanufacturing & tools, nanobiotechnology in our previous research by using Engineering Index (EI) defined by

performance of nanotech research systems by using bibliometric indicators (volumes of scientific publications) as a measure of the output of the research system – which helped illustrate the existing status and forecast future developments of nanotechnology (Miyazaki and Islam 2007). The variation of scientific output of specific domains related to nanotech over time is illustrated in Figure 1, where materials and electronics domains show their superiority in the volume of publications. The overall output has increased slowly from the mid 1990s and then sharply in the early 2000s, probably due to the establishment of nanotechnology initiatives such as NNI (National Nanotechnology Initiative) by the US government and the rest of world followed them. In the case of other two technology domains such as biotechnology and manufacturing & tools, research activity is slowly picking up, which is instructive that they are emerging fields for nanotech. Nanotechnology has been characterized as a field of more inter-disciplinary nature than other areas of science, since manipulating atoms and molecules at nanometer level plays a crucial role, where the classical laws of traditional science disciplines do not readily apply. Table 1 shows how nano-knowledge is co-created through technology domains, as the percentage volume data of publications illuminate a bridge through technology domains, instead of showing its majority in one discrete area. This finding is so instructive that nanotech research has mastered a diversity of areas that originated from different technology sectors, such as materials science, biotech, electronics and engineering & manufacturing to establish it as an inter-disciplinary field. We also turned our investigation on whether any overlapping of nano-knowledge creation through domains exist or not, and if so how much is the overlapping interest. Table 2 presents a correlation chart between specific domains, calculated by software called Vantage Point (Porter and Cunningham 2005) for the entire set of 28,559 articles. Very low correlations between technology domains suggest that there are no direct overlaps between the singled out domains, even though many articles are classified as belonging to two domains. If the analysis showed high correlation, there might be overlapping of nano-knowledge creation or research interests. However, very small values of the finding are instructive that nanotech knowledge has been co-created with the divergence of technology domains. We then developed a model for nano-knowledge co-creation through technology sectors, as illustrated in Figure 2.

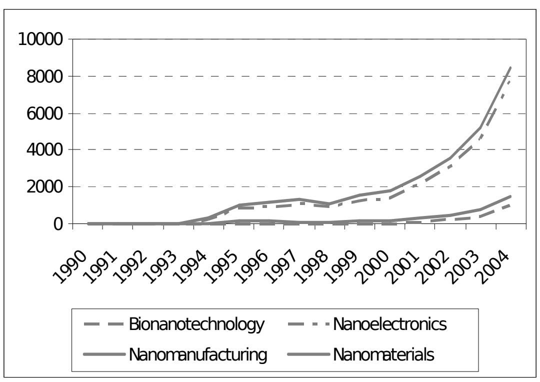

Fig.1: Nanoscientific output by technology domains

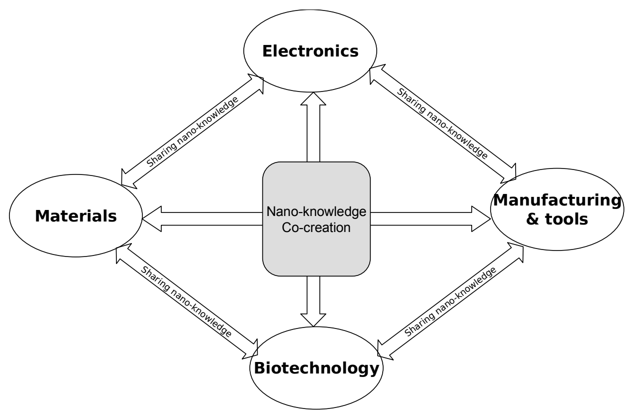

Fig.2: Nano-knowledge co-creation model through domains

Table 1: Nano-knowledge co-created with the divergence of technology domains

	Materials	Electronics	Manufacturing	Biotechnology
Materials	44.42	13.65	32.99	8.91
Electronics	8.33	48.65	34.61	8.40
Manufacturing	10.08	17.34	62.48	10.08
Biotechnology	8.8701	13.69	32.78	44.64

Table 2: Nano-knowledge co-creation without overlapping of technology sectors

Total No. of Pub. by Domains	Nanotech Domains	Materials	Electronics	Manufacturing	Biotechnology
28019	Materials	1.00	0.01	-0.02	0.04
24267	Electronics	0.01	1.00	-0.07	0.01
3847	Manufacturing	-0.02	-0.07	1.00	-0.03
1919	Biotechnology	0.04	0.01	-0.03	1.00

Elsevier Compendex. For every domain, detailed lists of relevant EI codes were identified – specific domains corresponded in general to distinctive EI classes (bionanotechnology: EI code 4.x, nanoelectronics: EI codes 6.x and 7.x, nanomaterials: EI codes 5.x and 8.x, nanomanufacturing/tools: EI code 9.x)]

MODEL OF NANO-KNOWLEDGE CREATION THROUGH SCIENTIFIC DISCIPLINES

We then investigated the pattern of nano-knowledge creation through scientific disciplines in the case of an important and major domain such as nanomaterials, based on related specific search keywords, derived from Nano Science and Technology Institute (NSTI) publications. For this, we have searched for scientific output from each discipline related to nanotech using SCI database and analyzed the reference citations to different disciplines. As demonstrated in Figure 3, it indicates that each disciplines' cited references were strongly linked with the respective disciplines rather than other disciplines in the earlier period such as in 1995, whereas this pattern has changed recently such as in 2005 sharing nano-knowledge with other disciplines. In the case of chemistry discipline, the share of cited references from chemistry related areas was 64.47% 10 years ago, but this ratio has dropped to 40.65% at present. In the case of physics, material science and biology, it has dropped from 74.39% to 53.71%, 39.02% to 29.15% and 54.12% to 36.02% respectively. On the other hand, the share of cited references from other disciplines has grown over the last 10 years period, which implies that in the earlier period, every discipline had less orientation to share nano-knowledge or link with other disciplinary knowledge, but rather this pattern has changed recently probably due to nano scale. With the evolution of nanotech, the basic research pattern by disciplines has been changing over period e.g., from more separate disciplinary knowledge culture to a more multi-disciplinary nano-knowledge culture (i.e., moved from a system or a culture of specific fields or topics into something that is co-creating at nano-scale). This trend may have been caused by the introduction of new nanomaterials such as carbon nanotubes and fullerenes as well as development of techniques for conducting research sparingly in nano-scale (e.g. introduction of nano-instruments: STM, AFM etc) to control and manipulate materials at this super small scale.

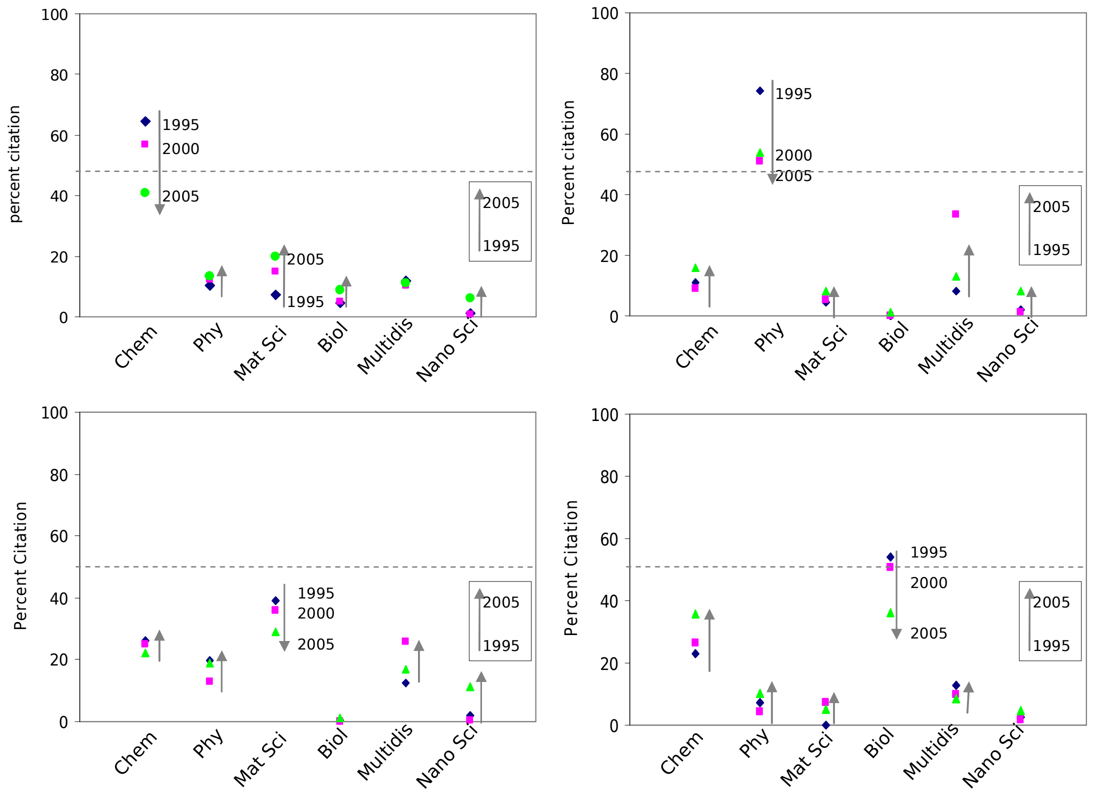

Fig.3: Nano-knowledge creation through scientific disciplines

Nanotechnology leads to a break down of the boundaries of all scientific disciplines and certainly does not allow a specific disciplinary knowledge, rather blurring of multi-disciplinary domains, since the classical laws of traditional science disciplines do not readily apply in nano-scale. Therefore, expertise of science disciplines needs to interact with researchers from other disciplines to share their nano-knowledge to uptake more efficient outcome with pervasive applications into almost all areas of interest through nanotechnologies. Since it seems almost impossible to conduct research in nanotech area without having strong connection of science and engineering disciplines[3]. For example, scientists who were conducting research on simply chemistry or photochemistry, tend to move now into photonics or physics for semiconductor as well as optics and electrical engineering in nano dimension. It is obvious to conceptualize by developing a model that nano-knowledge has been co-created through multiple disciplines, as illustrated in Figure 4.

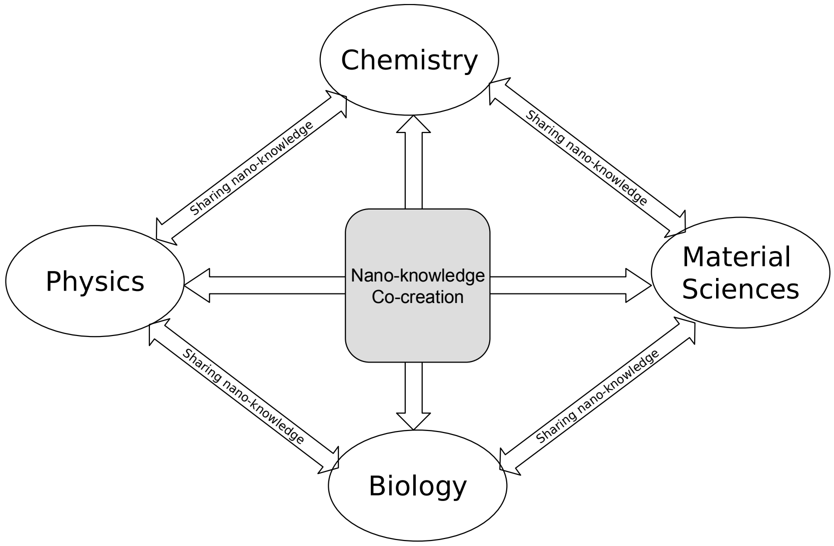

Fig.4: Nano-knowledge co-creation model through disciplines

CONCLUSION

The paper has explored the overall nano-knowledge co-creation process through scientific disciplines as well as technology domains and developed models for nanotech knowledge co-creation based on a combination of data by querying both quantitative and qualitative search. The models, it has been argued, represents a needed real-time analysis on the exploration of nanotechnological trajectories, which set hype over scientific and technological research community. We have envisioned that our models would particularly be important for nanotechnology evolution process and certainly capture the attributes related to co-evolutionary nature of nanotechnology. This exploratory analysis could help in forming technology strategies in the 21st century and science & technology policy makers might benefit by this emerging nanotechnological systems.

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