

Use of Integrated Knowledge Networks to Increase Innovation in Nanotechnology Research and Development

R. Byler

Abstract—Innovation, particularly in technology development, is a crucial aspect of nanotechnology R&D and, although several approaches to effective innovation management exist, organizational structures that promote knowledge exchange have been found to be most effect in supporting new and emerging technologies. This paper discusses Integrated Knowledge Networks (IKNs) and evaluates its use within nanotechnology R&D to increase technology innovation. Specifically, this paper reviews the role of IKNs in bolstering national and international nanotechnology development and in enhancing nanotechnology innovation. Both physical and virtual IKNs, particularly IT-based network platforms for community-based innovation, offer strategies for enhanced technology innovation, interdisciplinary cooperation, and enterprise development. Effectively creating and managing technology R&D networks can facilitate successful knowledge exchange, enhanced innovation, commercialization, and technology transfer. As such, IKNs are crucial to technology development processes and, thus, in increasing the quality and access to new, innovative nanoscience and technologies worldwide.

Keywords—Community-based innovation, integrated knowledge networks, nanotechnology, technology innovation.

I. INTRODUCTION

DEVELOPING countries face numerous challenges in deploying new science and technology (S&T) including disparate resource allocation, ineffective national policies, lack of delivery and support mechanisms, and weak intergovernmental coordination. It should be noted that the term “community” can be used nonspecifically to describe any collection of individuals, businesses, industries, or nations with a common goal [1]; however, for the purpose of this discussion, the term “community” is meant to describe a group united around shared technology R&D objectives, regardless of its size, membership, or specific focus area within nanoscience and technology. Throughout this paper, various statements about “communities” will be used; however, their overlying, shared characteristic is a collective interest in developing and deploying new S&T. In this manner, a “community” can also be called a network and, moreover, can be defined as either a physical or virtual entity [2]. Communities, regardless of how they are explicitly defined, allow for strategic knowledge sharing and decision-making

from which a basis greater than the sum of any one member or subgroup of members is created [3], [4]. This occurs since the collective knowledge, expertise, and ideas of individual community members are continually created, shared, iterated, and innovated in tandem with those of other members [5].

II. INNOVATION IN NANOTECHNOLOGY

A. Community-Based Innovation (CBI) Management

Community-Based Innovation (CBI) is a technology development method to utilize the existing innovative potential within a broadly defined “community” by increasing the interaction and information exchange between members [1], [5]. Designed around social network and interaction theories, CBI explicitly seeks to exchange existing innovation efforts, lessons learned, and tacit knowledge, as well as to facilitate crowd-sourced and/or collective capacity building [6]. CBI occurs through a three-stage innovation process within communities of shared R&D interests and varying degrees of knowledge concerning technology research, development, and commercialization [2], [3]. The first stage, *Idea Generation, and Concepts*, focuses on the exchange of knowledge and best practices with the goal of increasing innovation and end product value [4]. This stage is followed by *Design and Engineering*, which seeks to support end user exploration, cooperation among those developing similar products, and problem-solving through design testing and prototype iteration [3], [4]. The CBI process concludes with the *Test and Launch* stage, fulfilling collective goals via sharing and combining information on manufacturing, scale-up mechanisms, and TT [4], [6]. Thus, by focusing on the “community” as one entity, rather than its individual components, larger goals can be achieved, and more advanced enterprises can be established [1], [7]. For example, integrating ideas or connecting certain community members at different stages of S&T development can strengthen the ultimate objectives of collective innovation and cooperation in order to achieve shared goals [1], [3], [4].

Given this multi-stage process for effective CBI that yields successful product development and new businesses, it follows that there exists a need for deliberately organized communities and networks for innovation. In particular, the utilization of external management supports the purposeful organization of these communities (networks) for improved business outcomes [8]. Business innovation through strategically organized communities, such as the networks and

F. R. Byler is with the School of Engineering and Applied Science, Yale University, New Haven, CT 06511 USA (phone: 001-650-387-9397; e-mail: rebecca.byler@yale.edu).

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systems developed and facilitated by agencies such as the United Nations' Asia-Pacific Centre for Transfer of Technology (APCTT), is called CBI management [4]. Not only does CBI management allow for value-added product development via decentralization and integration of stakeholders, but it also enhances the organizational management of the community as well as the spread of information [5], [7].

B. Networks

Networks are the systematic establishment and management of internal and external cooperation among community members in order to improve performance or progress towards a shared goal [1], [8]. Networks are often used as sources of knowledge and innovation, as well as organizational structures to enhance the individual effectiveness of each member or stakeholder [10]. As such a "community" and a "network" can be considered analogous. Networks are an attractive CBI management practice since they allow open access to shared information, a wide range of capacity-building opportunities through interaction or explicit programs, and the ability to create and exchange tacit knowledge if centered around complex knowledge transfer, such as technology R&D [11], [12].

As the world becomes more globalized, it is becoming increasingly important to develop businesses and promote innovation through strategic community creation, particularly virtual community development via IT networks and platforms [5], [8], [11]. Virtual networks allow for increased collaboration with resources that are no longer bound by time or distance [13]. This allows for the activation of a figuratively unbounded CBI network, allowing for virtually limitless collaboration by extending the number of potential stakeholders and users [14]. In particular, virtual communities, including Innovation Networks and Integrated Knowledge Networks (IKNs), facilitate instantaneous information sharing related to design, development, manufacturing, and commercialization [11]. As a result, IKNs allow for community members to interact with each other at any hour of the day and to receive—and give—knowledge or skill training related to strengthening the capacity of the entire network in return [13]. Most importantly, virtual networks are also highly adaptive and facilitate a more flexible and coordinated platform for interactive, sustainable learning [4], [5]. In this sense, INKs can be thought of as dynamic structures that quickly and easily respond to changes in international policy or technology development and transfer needs.

Integrated Knowledge Networks (IKNs), or networks that combine organizational and technological elements that ultimately support the innovation process, are perhaps the most common example of dynamic, virtual CBI management support tools [10]. These innovation networks encompass a mixture of stakeholders, including individuals, enterprises, industries, universities/academia, and governments, and seek to optimize the interactions and relationships between the stakeholders and various times during the innovation process [4], [11]. For example, IKNs facilitate appropriate resource

dissemination, capacity building, and interaction in order to enhance innovation within the network. IKNs specifically promote knowledge creation and transfer, as a means of supporting a sustainable innovation process that can be replicated in the future in other "communities" without reliance on the IKN [10]. As this is the ultimate aim of nanotechnology development, IKN not only resonates well with researchers seeking collaborators and interdisciplinary applications, it is also implicitly incorporated into all of nanoscience and technology due to the method's reliance on facilitating processes rather than doing.

C. Case Study: APCTT

As one of five regional institutions of the United Nations in the Asia-Pacific, APCTT was established in order to manage S&T challenges with the objective of facilitating and strengthening technology transfer (TT) throughout Asia and the Pacific with a focus on technology enterprise development and support [16]. As such, the focus of APCTT is to assist in the development of S&T policies, collaborative technology innovation systems, and R&D management networks [15]. In particular, APCTT strengthens the R&D and intergovernmental capabilities of member countries by acting as a resource for management in science, technology, and innovation (STI), national innovation systems (NIS), TT, and technology intelligence. [16] As a result, APCTT plays a key role as the coordinator of capacity-building programs for Asia and the Pacific, facilitating opportunities for cross-border business cooperation among enterprises and promoting technology-based business partnerships and policies [15], [16]. As such, APCTT develops and manages a large number of IT-based networks and platforms for information exchange in priority or selected areas of technology, including renewable energy, nanotechnology, and sustainable agriculture, as well as works to identify gaps in regional knowledge and organize in-person capacity building programs to assist partner countries in generating more sustainable technology development and transfer themselves [15].

III. ANALYSIS OF CURRENT IKNS

Effective innovation management is a crucial aspect of any business or organization; however, it is especially important for APCTT given its overarching aim to increase technology innovation, development, and access in the Asia-Pacific via the development of self-enterprising member nations. Innovation, especially in technology development, is a vital tool for generating value and successful scale-up and commercialization [8]. Innovation inherently incorporates a wide array of participants and stakeholders including academics, governments, and industries, and, as a result, is highly reliant on the frequent—yet efficient—interaction and cooperative efforts between these role-players [9], [10]. Although several approaches to knowledge management are viable management strategies, organizational methods that promote knowledge exchange have been found to be the most effective in attaining these goals [1], [11]. The use of virtual IKNs have proliferated connectivity between the various role-

players and, additionally, have increased the amount of explicit and implicit knowledge that can be shared via Internet-based open-source platforms, databases, and online training resources or events [12], [13].

Given this, the role of CBI management through the use of virtual IKNs is an important management practice for academic institutions, researchers, and organizations such as APCTT. In fact, APCTT currently employs this effective technology innovation management tool in many of its programs. This paper will only discuss two uses of IKN in depth, NIS, and STI management, as the focus is on research and development of new technologies. However, IKNs are clearly used and applicable to other stages of technology development and dissemination, most notably TT, which is also briefly discussed. Although this discussion will build on the use of APCTT as a case study; overall, many other international organizations and research/academic institutions also effectively use IT-based IKN platforms to identify and support new and emerging technologies, assist with S&T capacity building initiatives, and facilitate international research collaboration in order to inform global nanoscience and technology innovation and R&D cooperation better. The precise role of the robust and dynamic virtual IKNs and CBI management practices by APCTT is further defined using its most ubiquitous applications of IKNs: NIS, STI, and TT.

A. National Innovation Systems (NIS)

Technology can address a variety of environmental and social challenges inherent to developing countries and, moreover, emerging technological advancements can increase employment, the food supply, and revenue [16]. For example, APCTT creates resources and organizes events to support Asia-Pacific countries in increasing technology use and creating a national foundation for continued nanotechnology development and commercialization [15]. In particular, APCTT strengthens NIS in order to reduce “the valley of death” between technology R&D and actually reaching the market [16]. Thus, APCTT effectively uses CBI management practices (IKNs) by 1) facilitating the development and evaluation of new and emerging technology initiatives; 2) providing an open platform for sharing expertise and increasing collaboration between industries, SMEs, R&D institutions, and universities/academia; and 3) creating an online knowledge database and network of international experts in STI that can learn from each other during both the R&D and commercialization phases. By managing both Indian and other Asia-Pacific institutions in new and emerging technology development and commercialization, and actively creating and enhancing university-industry R&D partnerships, APCTT helps regional institutions more sustainably define their business and policy needs for effective dissemination of new technologies and support of early-stage enterprises [15], [16].

B. Science, Technology, and Innovation (STI) Networks

Due to inherent differences in resources and capabilities across Asia-Pacific countries, APCTT aims to connect nations

via shared technology platforms to pursue mutual objectives through public-private partnerships and south-south collaboration [16]. To this end, APCTT creates active networks of S&T stakeholders in the Asia-Pacific with the goal of improving transnational technology policies, resource identification, commercialization, and scale-up/delivery mechanisms [15], [16]. In addition to creating broad capacity-building and information networks for the entire region, APCTT also creates specialized networks for specific technology focuses [16]. For example, APCTT created a Nanotechnology R&D Management Network to promote technology-based business partnerships within nanotechnology enterprises and to create a regional network of nanotechnology R&D institutions/enterprises [15], [16]. Overall, these IKNs allow for the collection/dissemination of relevant information, the sharing of best practices, and enhanced international collaboration in value-added product development to enhance the competitiveness of emerging technology enterprises. Thus, APCTT’s use of CBI management implicitly enhances international relations between Asia-Pacific governments and countries by supporting increased international R&D and commercialization/marketing collaboration and by sharing mutually beneficial technological developments [15].

C. Technology Transfer (TT)

APCTT offers TT facilitation services to technology providers/seekers via international partnerships and intermediary TT networks [16]. Knowledge of and access to technologies is paramount to successful international businesses; thus, capacity building of enterprises, including business case preparation; technology sourcing, assessment, pricing; and contract negotiation and finalization; is essential [16]. To this aim, APCTT organizes and facilitates networking events, technology exhibitions, and training workshops in its member countries [15]. APCTT also develops extensive online resources and IT platforms for TT including public resource manuals, open R&D technology databases, and publishes articles on key technology developments, technology policies, innovation management, and international TT for its periodical, Asia-Pacific Tech Monitor [16]. These online resources seek to increase public awareness about new and emerging technologies and expand international access of innovative technologies, while also directly supporting R&D Network stakeholders [15]. Additionally, APCTT also conducts transnational workshops and events to enhance international cooperation and enterprise management opportunities by uniting diverse research/industry perspectives, goals, and experiences to improve the development and dissemination of pertinent technologies across international borders [15], [16].

IV. FUTURE WORK

Evidence-based, quantitative validation of the developed CBI management networks (IKNs) is crucial to determining the functionality of the network and its ability to achieve desired results of facilitating innovation, the exchange of

knowledge and technology, and the capacity-building of its members. As such, developing a specific set of desired outcomes and metrics for determining success should always be a key area of focus. Nevertheless, since several measures for monitoring and evaluating progress, successes, and areas of need are already routinely used in IKNs, in order to improve nanoscience and technology innovation, expanding the reach of the innovation network is imperative. Given this, additional ideas for increasing the global access and use of virtual CBI management networks should be explored. Following a systematic review of 9 nanoscience and technology IKNs regarding the current gaps in linking network stakeholders, facilitating the use of extensive online knowledge base, and maximizing the impact of workshops and forums, it was determined that adding a smartphone application to supplement existing virtual IKN platforms (such as APCTT's R&D Management Networks) would greatly improve R&D innovation and the ability of researchers to more easily share knowledge for more effectively facilitating new technology development and transfer worldwide.

For this reason, the addition of smartphone applications to link IT-platforms, online networks, and in-person R&D events is recommended in order to more effectively target new researchers and stakeholders. For example, most IKNs only exist as internet-based IT platforms for its innovation and R&D networks. However, Internet users only constitute 1.21 billion people in the Asia-Pacific [17]. Conversely, the Asia-Pacific has 2.5 billion mobile phone users—more than half of the world's mobile phone users—of which 783.2 million own smartphones [17]. This percent is expected to proliferate over the next decade and, in fact, internet access in the Asia-Pacific is often mobile-first, indicating that developing phone-based strategies for technology innovation might be more accessible and allow for network expansion [13]. This would subsequently strengthen the nanoscience and technology R&D and enterprise development capabilities of by increasing the number and quality of platforms available for information exchange in selected areas of technology.

V. CONCLUSION

Most researchers successfully utilize CBI management in its NIS and STI R&D Management Networks, primarily through the use of IT-based platforms such as virtual IKNs. The use of these management practices directly contributes to the global success of nanoscience and technology research. Thus, since traditional research networks are geographically bound in creating opportunities for cross-border business cooperation among enterprises and promoting technology-based business partnerships and policies, the correct integration of CBI and IKNs to facilitate enhanced innovation and business development are paramount. Although current nanotechnology research has shown to be highly innovative and with scale-up potential, such as the successful agricultural nanotechnology transfer for improved food security that has reduced the percent of undernourished people from 27% to 17.5% in the Asia-Pacific [18], improvements can still be made to improve the efficacy of these CBI network systems.

As such, it is suggested that INKs expand its IT-platform to include a smartphone-based application for enhanced interaction among its network stakeholders for improved access to its currently available STI and TT resources. It is hypothesized this will improve R&D, enterprise development, and TT, directly improving the innovative capacity of nanoscience and technology research.

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