KNOWLEDGE SCIENCE – MODELING THE KNOWLEDGE CREATION PROCESS

Yoshiteru Nakamori
School of Knowledge Science, Japan Advanced Institute of Science and Technology,
1-1 Asahidai, Nomi, Ishikawa 923-1292, Japan
E-mail: nakamori@jaist.ac.jp

Knowledge science is a problem-oriented interdisciplinary field that takes as its subject the modeling of the knowledge creation process and its application, and carries out research in such disciplines as knowledge management, management of technology, support for the discovery, synthesis and creation of knowledge, and innovation theory with the aim of constructing a better knowledge-based society. This paper considers what knowledge science should be, introducing a forthcoming book entitled *Knowledge Science – Modeling the Knowledge Creation Process* (Nakamori ed., 2011). The authors of this book are experienced researchers in knowledge science with the background of systems science, and core members of the *International Society for Knowledge and Systems Sciences*. This book introduces six important concepts in knowledge science, which are knowledge technology, knowledge management, knowledge discovery, knowledge synthesis, knowledge justification, and knowledge construction. Finally, the paper briefly describes a theory of knowledge construction systems; its fundamental part was already published in Systems Research and Behavioral Science (Nakamori et al., 2011)

Keywords: knowledge technology; knowledge management; knowledge discovery; knowledge synthesis; knowledge justification; knowledge construction

SCHOOL OF KNOWLEDGE SCIENCE

The School of Knowledge Science at Japan Advanced Institute of Science and Technology (JAIST) started education in April 1998, which is the first school established in the world to make *knowledge* a target of science. The first dean of the School was Professor Ikujiro Nonaka who is famous worldwide for his organizational knowledge creation model called the SECI spiral (Nonaka and Takeuchi, 1995), which is in fact the key factor in establishing the School.

The theory of organizational knowledge creation suggests that new knowledge is created by the interaction between explicit and tacit knowledge through the spiral of *Socialization*, *Externalization*, *Combination*, and *Internalization*:

Socialization is a process of sharing experiences and thereby creating tacit knowledge such as shared mental models and technical skills.

Externalization is a process of articulating tacit knowledge into explicit concepts, taking the shape of metaphors, analogies, concepts, hypotheses, or models.

Combination is a process of linking explicit knowledge to obtain a knowledge system.

Internalization is a process of embodying explicit knowledge into tacit knowledge. It is closely related to learning by doing.

This principle is revolutionary because it stresses steps leading to knowledge increase surely, based on the collaboration of a group in knowledge creation and on the rational use of irrational mind capabilities, namely tacit knowledge, which includes emotions and intuition.

When establishing a new school, the founding members had to distinguish knowledge from information, which is necessary to explain the structure of the School. *Information is knowledge transmitted by character, sign, voice, etc., or data arranged to be useful for decision making*. Thus, information is a relative word; which is sometimes knowledge of other person's, and sometimes just collected data. On the other hand, *knowledge is recognition memorized personally or socially, or judgment or a system of judgment which has objective validity*. Using knowledge of the latter definition, people transform data into information, and information into knowledge.

What is the energy to bring such transformation? We can call it intelligence. Intelligence has several meanings, but here we consider computers' ability to judge things automatically, or people's ability to understand and learn things. This consideration suggested the structure of the School, which should consists of:

Information Science to develop computers' ability to judge things automatically, and

Management Science to enhance people's ability to understand and learn things.

However, knowledge treated in information science is mainly explicit because we have to convey knowledge through computer codes, while important knowledge in management science is tacit; it is quite difficult to transfer people's knowledge to others with words. This is the reason why we require the third discipline:

Systems Science to strengthen system's ability by integrating a diversity of knowledge.

In the management field, the School of Knowledge Science at JAIST is proud to have pioneered research into knowledge creation theory. Regarding information technology, it has been developing knowledge creation support systems. Systems theory research regarding knowledge integration and creation offers tools and techniques in consultation to business and society. The School will integrate these fields at the interdisciplinary project level, and to facilitate innovation in a variety of fields.

However, at the present stage, knowledge science is more a problem-oriented interdisciplinary academic field than a single discipline. Its mission is to organize and process both objective and subjective information and to create new value, new knowledge. Knowledge science mainly deals with the research area involving social innovation such as regeneration of organizations, systems and the mind. However, society's progress is underpinned by technology, and the joint progress of society (needs)

and technology (seeds) is essential. Therefore, knowledge science also has the mission to act as a coordinator (intermediary) in extensive technological and social innovations.

In order to fulfill these missions, the School of Knowledge Science focuses its research and education on observing and modeling the actual process of carrying out the mission, as described in the organizational knowledge creation theory by Nonaka and Takeuchi (1995), or the creative space theory by Wierzbicki and Nakamori (2006), as well as developing methods to carry out the mission. The methods are mainly being developed through the existing three areas in the School. These are:

The application of business science/organizational theories (practical use of tacit knowledge, management of technology, innovation theory).

The application of information technology/artistic methods (knowledge discovery methods, ways to support creation, knowledge engineering, cognitive science).

The application of (mathematical) systems theory (systems thinking, the emergence principle, socio-technical systems).

APPROACHES TO KNOWLEDGE SCIENCE

We could count several research fields related to knowledge science:

Knowledge engineering symbolizes (approximates) experts' knowledge to develop artificial intelligence.

Knowledge discovery mines a large scale of data set to extract partial rules, and adds their meanings, using domain knowledge.

Knowledge construction simulates complex phenomena based on some hypothesis, and adds the meanings of emerged properties, using domain knowledge.

Knowledge management tries to convert distributed (or tacit) knowledge into shared (or explicit) knowledge, and uses it effectively.

The feature of these fields is the use of computers, expanding traditional information science; which means that these fields use subjective knowledge.

Organizational knowledge creation is the key factor to establish the School of Knowledge Science; but after the SECI spiral, some different spirals were proposed. The feature of these knowledge creation models is the use of persons directly beyond information science. While the SECI spiral is a bottom-up type, Gasson (2004) proposed a top-down type model by analyzing possible transitions between the same four nodes (but group knowledge is called shared knowledge while individual knowledge is called distributed knowledge) in the organizational culture of a Western company. Wierzbicki et al. (2006) proposed *personal knowledge creation* models which correspond to

disciplinary knowledge creation. Feature of these models is to use persons directly, beyond information science.

However, to solve complex real-life problems we need *knowledge synthesis*, collecting and interpreting different types of knowledge from cognitive-mental front, scientific-factual front, and social-relational front. We have been trying to establish a theory related to knowledge synthesis because we believe that the most important task is knowledge synthesis in knowledge science as well as systems science. We have just published a first version of the theory in Systems Research and Behavioral Science (Nakamori et al., 2011); a brief summary will be given later in this paper.

Nonaka et al. (2000) called the dynamic context which is shared and redefined in the knowledge creation process 'Ba', which does not refer just to a physical space, but includes virtual spaces based on the Internet, for instance; and more mental spaces which involve sharing experiences and ideas. They stated that knowledge is not something which can exist independently; it can only exist in a form embedded in 'Ba', which acts as a context that is constantly shared by people.

From the hypothesis that knowledge science will be established at the 'Ba' where three disciplines are integrated, we should expand our research into social and technological innovation to foster revitalization projects and collaborative projects with enterprises.

Here is an example: Suppose that a student participates in the Biomass Town Project of a certain city. If the main theme is the extent of reductions in the concentration of carbon dioxide and an analysis of the economic effects, and the secondary theme is converting food residue into ethanol, the student will receive guidance from the School of Materials Science for the secondary theme. In addition, the qualities of a coordinator will be required such as in requesting assistance from the public to further the project, mediating between the parties concerned, and collating and providing data and opinions. In such a case we will request the municipal representative to act as a mentor and to contribute to the student's growth. Moreover, if for example the technology to turn Malaysian palm oil to ethanol is provided, and ethanol successfully imported and marketed, this will contribute to both the revitalization of the regional economy and the expansion of international activities. We can call such people the social and technological innovators.

Our tasks in a knowledge-based society could be classified into the following three areas: The first is to use information technology and systems science, and the management of technology and knowledge, to support the creation of knowledge and technology (to create technological innovation). The second is to reform social systems and people's minds to make effective use of advances in knowledge and technology (to create social innovation). The third is to nurture leaders who can accomplish the first and second tasks and construct a better knowledge-based society (to nurture innovators).

Such leaders require the abilities of knowledge workers and innovators in wide-ranging areas (called "knowledge creators"). However they cannot achieve satisfactory results unless they possess the ability to coordinate the opinions and values of diverse people

(called "knowledge coordinators"). Accordingly, we should aim to promote cutting-edge research into the theory and practices of social innovation, and technological innovation.

CONTENTS OF THE BOOK: KNOWLEDGE SCIENCE

This paper introduces a new book entitled Knowledge Science – Modeling the Knowledge Creation Process. The prospective readers of this book are researchers, practitioners, especially graduate students in the fields of knowledge management, information science, management science, sociological systems science, etc. The authors of this book are experienced researchers in knowledge science with the background of systems science. Young researchers will find new research theme from this book as well as the importance of knowledge science.

This book introduces six important concepts in knowledge science: knowledge technology, knowledge management, knowledge discovery, knowledge synthesis, knowledge justification, and knowledge construction. Knowledge technology is an umbrella term, which includes subsequent concepts above, and also includes knowledge classification, representation and modeling, knowledge identification and acquisition, knowledge searching, knowledge organization, knowledge storage, knowledge conversion, knowledge dissemination, etc.

Knowledge management is the prime keyword in knowledge science research. This book introduces the theories and practices of knowledge-oriented management in organizations, which covers purposeful coping of three differentiated yet related areas: knowledge assets, knowing processes and knower relations. Knowledge discovery and data mining emerged as a rapidly growing interdisciplinary field that merges together databases, statistics, machine learning and related areas in order to discover and extract valuable knowledge in large volumes of data.

Knowledge synthesis, knowledge justification, and knowledge construction are quite important when solving real-life problems. This book introduces the original ideas by respective contributors to corresponding chapters, which include Oriental systems philosophy, a new episteme in the knowledge-based society, and a theory of knowledge construction.

In the chapter of Knowledge Technology, Zhongtuo Wang, from the School of Management at Dalian University of Technology in China, describes knowledge technology, which can be understood as a new emerging discipline applying the outcome of principles of knowledge science to knowledge processing, knowledge management, and knowledge creation. Considering the important role of systems science in providing methodology and techniques for organization and management of human endeavors, the author proposes to establish a new branch of systems engineering called "knowledge systems engineering" for a new approach to knowledge processing and knowledge management, which differs from "knowledge engineering" in artificial intelligence at its area of study not only limited to the technological aspect but also concerned with organizational and cognitive aspects. After discussing the architecture of knowledge

systems, the author describes definitions and roles of many concepts related to knowledge technology such as the knowledge-gathering and -capturing technology and systems, including the technologies and tools as databases and text bases, data warehouse and data marts, web technologies, cloud computing, knowledge repositories, knowledge portals, search engines, intelligent agents, and knowledge maps. For the system support of knowledge discovery and creation, the author describes both the discovery of explicit knowledge and technological aid for idea generation and some knowledge-sharing technology and systems like lesson learned system, expertise-locator system, and community of practices. For the knowledge application system, the author describes some mechanisms and technologies, including the help desk, fault diagnosis systems, expert systems, as well as decision support systems.

In the chapter of Knowledge Management, Zhichang Zhu, from the University of Hull Business School in the United Kingdom, considers this topic from a systems-theoretic point of view. First the author answers to the questions: Why has knowledge management considerably promoted recent years? What is knowledge, and is it manageable? Then, the author takes a pragmatic approach to knowledge-based management that gears managerial efforts and organization resources to the following: get the knowledge vision right, focus on organizational management, and make it work in particular contexts. Adopting a pragmatist and holistic perspective, the author introduces readers to the theories and practices of knowledge-oriented management in organizations, which covers purposeful coping of three differentiated yet related areas: knowledge assets, knowing processes, and knower relations. The author also suggests that a systems approach promoting synergy among efficiency, creativity, and legitimacy will increase opportunities for organizations in the search for competitive advantage and sustainable prosperity. This chapter itself is a conscious attempt in bridging systems and knowledge sciences with an explicit focus on enhancing organizational management practice.

The chapter of Knowledge Discovery, by To Bao Ho of the School of Knowledge Science at Japan Advanced Institute of Science and Technology, discusses how knowledge discovery and data mining (KDD) emerged as a rapidly growing interdisciplinary field that merges together databases, statistics, machine learning, and related areas to discover and extract valuable knowledge in large volumes of data. The knowledge discovery addressed in this chapter is an information science ingredient of knowledge science, which is essentially the finding or discovering knowledge in data. It is an interdisciplinary field, having roots in the new field of knowledge discovery and data mining in the last two decades. Almost all organizations have collected huge amounts of data in their databases. These organizations need to understand their data or to discover useful knowledge as patterns or models from their data. Meeting this increasing need in the digitalized society, KDD has been becoming an attractive science and technology in both theory and practice. The author provides basic concepts and methods of KDD as well as its typical applications and begins with an overview of data, information, and knowledge. Then, definitions of *knowledge discovery* and *data mining* are provided, followed by the steps in the KDD process. The main part of the chapter covers the essential ideas of typical KDD methods and the challenges and trends of KDD

after its 15 years of development. Finally, text mining—a typical branch of KDD—and its application are briefly introduced.

In the chapter of Knowledge Synthesis, by Jifa Gu of the Institute of Systems Science at the Chinese Academy of Sciences in China, the author discusses that the most common knowledge can be recognized by the majority of people. However, due to the methods of getting data, information, and knowledge from different sources or inferring knowledge by using different mechanisms, under most circumstances, people will use different kinds of knowledge to express their own thoughts at first and through discussing and even debating with others may use synthesis to reach consensus. It means that some knowledge can be recognized only through the synthesis of thoughts. Then, during implementation, in which people put the knowledge into practice, they have to use synthesis of actions. The author first introduces various definitions of knowledge synthesis, and then several existing approaches to knowledge synthesis. Among them, the author's original works are the meta-synthesis system, which is useful for synthesis of thoughts; and the Wuli-Shili-Renli system, which is useful for synthesis of actions. The author also introduces expert mining, which helps to dig deep thoughts from individual experts or a group of experts. Finally, the author provides some case studies in the fields of economic, social, and human body systems.

The chapter of Knowledge Justification, by Andrzej Wierzbicki of the Poland National Institute of Telecommunication, presents another perspective of viewing knowledge technology and science: *How does knowledge evolve? How do we justify knowledge, that is, check whether new knowledge is correct and useful? What is specific in knowledge justification in the new era after informational revolution?* The author starts with what is "today" in the beginnings of the era of knowledge society; then turns to what we mean by "knowledge" and "episteme," the way of creating and justifying knowledge characteristic for a given era or cultural sphere. The author discusses the naturally circular, positive feedback type of knowledge creation and justification processes that, contrary to a tradition in philosophy, are not a paradox but are natural evolutionary phenomena. The author shows how we should look today at the processes of knowledge creation and what are accepted methods of justifying knowledge. Finally, the author presents diverse spirals of knowledge creation and discusses the principles of developing a new episteme of the era of knowledge civilization.

Finally, the chapter of Knowledge Construction, by Yoshiteru Nakamori of the School of Knowledge Science at Japan Advanced Institute of Science and Technology, considers the problem of knowledge construction and proposes a theory of knowledge construction systems, which consists of three fundamental parts: a knowledge construction system; a structure–agency–action paradigm; and evolutionary constructive objectivism. The first is a model of collecting and synthesizing knowledge; the second relates to necessary abilities of actors when collecting knowledge in individual domains; and the third comprises a set of principles to justify collected and synthesized knowledge. The author starts with a brief introduction of a basic systems approach called "informed systems thinking", followed by a summary of the theory of knowledge construction systems. The author then explains its three fundamental parts with an explanation of characters of the

theory. Finally, the author concludes that we should nurture talented people, called "knowledge coordinators". How can we nurture such people? One of the answers is that we should establish knowledge science, educate young students by this discipline, and encourage learning by doing.

The last topic: knowledge construction will be summarized in the next section.

SUMMARY OF THE THEORY OF KNOWLEDGE CONSTRUCTION

Wierzbicki et al. (2006) proposed redefining systems science as the discipline concerned with methods for the *intercultural* and *interdisciplinary* integration of knowledge, including soft inter-subjective and hard objective approaches, *open* and *informed* attitudes.

Intercultural means an explicit accounting for and analysis of national, regional, even disciplinary cultures, trying to overcome the incommensurability of cultural perspectives by explicit debate of the different concepts and metaphors used by diverse cultures.

Interdisciplinary approach has been a defining feature of systems science since Comte (1844), but has been gradually lost in the division between soft and hard approaches.

Open and *Informed* mean pluralist:

Not excluding by design any cultural or disciplinary perspectives, as stressed by soft systems approaches (Linstone, 1984; Jackson and Keys, 1984; Flood and Jackson, 1991).

Not excluding any perspectives due to ignorance or disciplinary paradigmatic belief, as stressed by hard systems approaches.

A basic novel understanding related to the above thinking is the essential extension of the skeleton of science (Boulding 1956). Wierzbicki et al. (2006) named the above thinking *Informed Systems Thinking*, which consists of three principles:

The principle of cultural sovereignty: We can treat all separate levels of systemic complexity as independent cultures, and generalize from basic cultural anthropology: no culture shall be judged by using concepts from a different culture.

The principle of informed responsibility: No culture is justified in creating a cultural separation of its own area; it is the responsibility of each culture to inform other cultures about its own development, and be informed about development of other cultures.

The principle of systemic integration: Whenever needed, knowledge from and about diverse cultures and disciplines may be synthesized by systemic integration, be they soft or hard, without a prior prejudice against any of them.

It is, however, quite difficult to execute the principle of systemic integration unless we have theories or methods for knowledge construction. A summary of *the theory of knowledge construction systems* is given below, which consists of three fundamental parts:

The knowledge construction system: A basic system to collect and synthesize a variety of knowledge, called the *i*-System, which itself is a systems methodology (Nakamori, 2000, 2003).

The structure-agency-action paradigm: A sociological interpretation of the *i*-System to emphasize the necessary abilities of actors when collecting and synthesizing knowledge (Nakamori and Zhu, 2004).

The evolutionary constructive objectivism: A new episteme to create knowledge and justify collected and synthesized knowledge (Wierzbicki and Nakamori, 2007).

The main characteristics of this theory are:

Fusion of the purposiveness paradigm and purposefulness paradigm: With the *i*-System, we always start by searching for and defining the problem according to the purposefulness paradigm. Since the *i*-System is a spiral-type knowledge construction model, in the second cycle we use the *i*-System to find solutions according to the purposiveness paradigm. However, it is almost always the case that when we find an approximate solution, we face new problems.

Interaction of explicit knowledge and tacit knowledge: An important idea of Nonaka and Takeuchi (1995) is that new knowledge can be obtained by the interaction between the explicit and the tacit knowledge. The use of the *i*-System means that we must inevitably deal with objective knowledge such as scientific theories, available technologies, social-economic trends, etc. as well as subjective knowledge such as experience, technical skills, hidden assumptions, paradigms, etc.

Involvement of knowledge coordinators: The theory requires people who accomplish the knowledge synthesis. Such persons need to have the abilities of knowledge workers and innovators in wide-ranging areas. However, they cannot achieve satisfactory results unless they also possess the ability to coordinate the opinions and values of diverse people. An educational system should be established to train human resources who will promote knowledge synthesis in a systemic manner.

REFERENCES

Boulding K (1956) General systems theory: The skeleton of science. *Management Science* **2**: 197-208.

Comte A (1844) *A General View of Positivism* (translation in 1865), London.

Flood RL, Jackson MC (1991) *Creative Problem Solving: Total Systems Intervention,* John Wiley and Sons.

Gasson S. (2004) The management of distributed organizational knowledge. In Sprague RJ (ed) *Proceedings of the 37th Hawaii International Conference on Systems Sciences* (CD/ROW). IEEE Computer Society Press.

Jackson MC, Keys P (1984) Towards a system of systems methodologies, *Journal of the Operational Research Society* **35**: 473-486.

Linstone HA (1984) *Multiple Perspectives for Decision Making*, North-Holland.

Nakamori Y (2000) Knowledge management system toward sustainable society. In *Proceedings of the 1st International Symposium on Knowledge and System Sciences* 57-64, September 25-27, JAIST, Japan.

Nakamori Y (2003) Systems methodology and mathematical models for knowledge management, *Journal of Systems Science and Systems Engineering* **12**(1): 49-72.

Nakamori Y ed. (2011) Knowledge Science – Modeling the Knowledge Creation Process. Taylor & Francis,
to be published in July, 2011.

Nakamori Y, Zhu ZC (2004) Exploring a sociologist understanding for the *i*-System. *International Journal of Knowledge and Systems Sciences* **1**(1): 1-8.

Nakamori Y, Wierzbicki AP, Zhu ZC (2011) A theory of knowledge construction systems. *Systems Research and Behavioral Science*, Vol.28, pp.15-39, 2011.

Nonaka I, Takeuchi H (1995) *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation*. Oxford University Press: New York.

Nonaka I, Toyama R, Konno N (2000) SECI, ba and leadership: A unified model of dynamic knowledge creation. *Long Range Planning* **33**: 5-34.

Wierzbicki AP, Nakamori Y (2006) *Creative Space: Models of Creative Processes for the Knowledge Civilization Age*. Springer-Verlag: Berlin-Hidelberg.

Wierzbicki AP, Nakamori Y, eds. (2007) *Creative Environments: Issues of Creativity Support for the Knowledge Civilization Age.* Springer-Verlag.

Wierzbicki AP, Zhu ZC, Nakamori Y (2006) A new role of systems science: informed systems approach, In *Creative Space: Models of Creative Processes for the Knowledge Civilization Age* Wierzbicki AP, Nakamori Y (eds.), 161-215, Springer-Verlag.