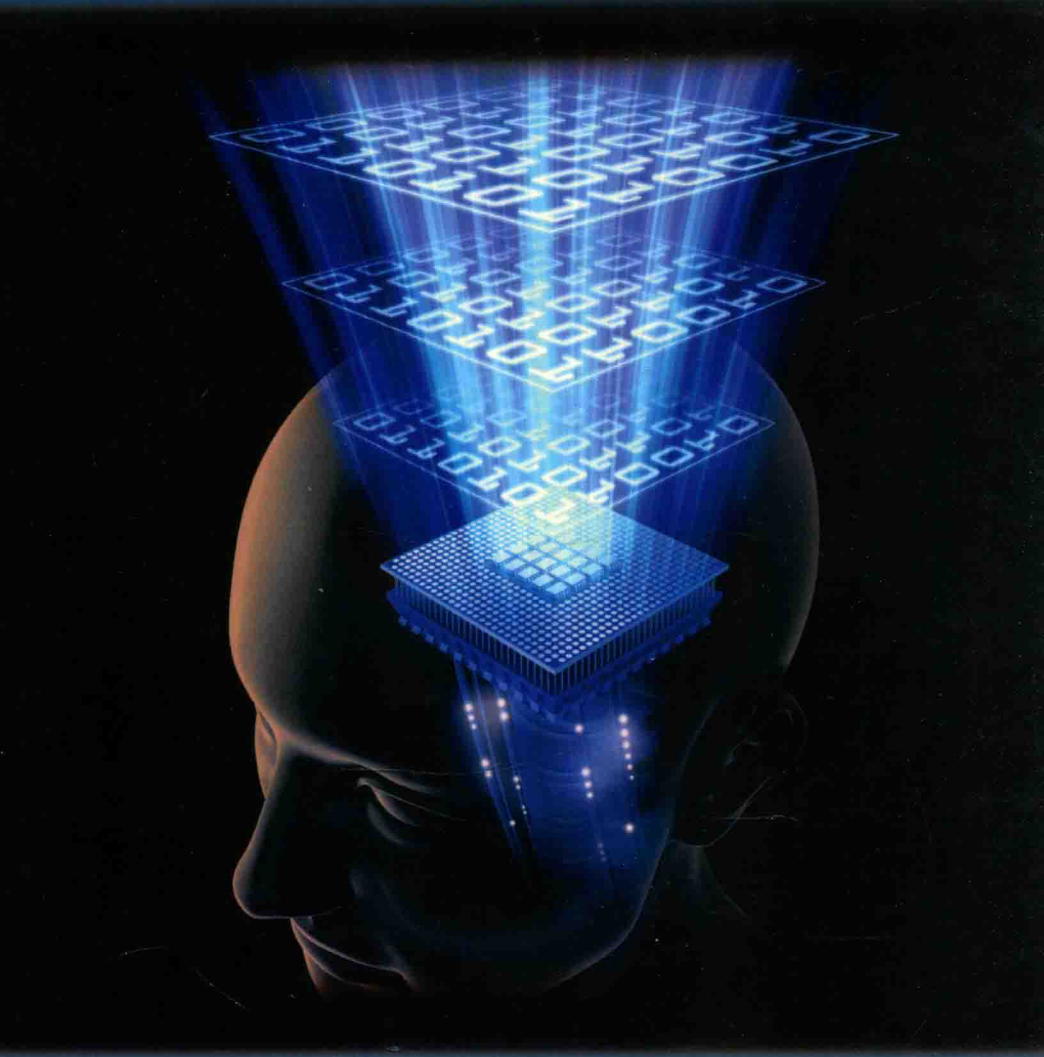
# Knowledge Science

## Modeling the Knowledge Creation Process



Edited by

Yoshiteru Nakamori

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# Knowledge Science

## Modeling the Knowledge Creation Process

# *Preface*

Knowledge science is a problem-oriented interdisciplinary field that takes as its subject modeling of the knowledge creation process and its application and carries out research in disciplines such 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.

Knowledge science develops methodologies and techniques for the management of knowledge and technology; for the discovery, creation, and structuring of knowledge; and for solving organizational and systemic problems. It coordinates various forms of knowledge such as opinions, values or information, science, technology, and diverse standpoints such as industry, academic, government or private sectors. Knowledge science could be established by integrating information science, management science, and systems science.

On the education side, knowledge science produces talented graduates who are capable of comprehensively examining a variety of social issues such as developments in technology, economic–commercial activities, depopulation–aging of society, global warming–depletion of resources, or the stagnation of regional economies, and taking the lead in solving them.

Knowledge engineering (a branch of information science) is mainstream in the world of knowledge science. But knowledge science should aim for integration with knowledge management (for example, human management), the importance of which is recently garnering worldwide attention. However, it will theoretically take some time to integrate the aforementioned three fields and to establish a new academic system. One of the reasonable ways is to attempt their integration in practical use (problem-solving projects), to accumulate actual results, and then to establish them as a discipline in a new field.

Prospective readers of this book are researchers, practitioners, and especially graduate students in the fields of knowledge management, information science, management science, and sociological systems science. The authors of this book are experienced researchers in knowledge science with backgrounds in systems science. Young researchers will find in this book new research themes as well as the importance of knowledge science.

This book introduces six important concepts in knowledge science: (1) knowledge technology, (2) knowledge management, (3) knowledge discovery, (4) knowledge synthesis, (5) knowledge justification, and (6) knowledge construction. Knowledge technology is an umbrella term that includes the previously mentioned concepts as well as knowledge classification, representation and modeling, knowledge identification and acquisition, knowledge

searching, knowledge organization, knowledge storage, knowledge conversion, and knowledge dissemination.

Knowledge management are the keywords in knowledge science research. This book introduces the theories and practices of knowledge-oriented management in organizations and covers three different yet related areas: knowledge assets, knowing processes, and knower relations. Knowledge discovery and data mining emerged as a rapidly growing interdisciplinary field that merges databases, statistics, machine learning, and related areas 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 includes original ideas, such as Oriental systems philosophy, a new episteme in the knowledge-based society and a theory of knowledge construction.

**Yoshiteru Nakamori, Editor**

# *About the Authors*

**Jifa Gu** received a B.S.c. from Peking University in China and a Ph.D. from the Institute of Mathematics at the Academy of Sciences of the USSR. He is a professor in the Institute of Systems Science at the Chinese Academy of Sciences, a part-time professor at Dalian University of Science and Technology, and a part-time professor at the graduate school at the Chinese Academy of Sciences; from May 1999 to March 2003 he was a professor at the Japan Advanced Institute of Science and Technology. Beginning in 2005, he has served as the joint director of Shanghai Academy of Systems Science. He has also served as the president of the Systems Engineering Society of China (1994–2002); president (2002–2006) and vice president (2006–2008) of the International Federation for Systems Research; vice president of the International Society of Knowledge and Systems Sciences (2003–2008); and chief editor of *Journal of Systems Science and Systems Engineering* (2003 to present). He has published more than 200 papers and 30 books and has organized several international conferences in the fields of systems engineering, operations research, industrial engineering, and knowledge science. Gu's recent research interests include meta-synthesis methods and system methodology. His current research aims to find methods that may synthesize the data, information, model, knowledge, and the decision maker's judgment and wisdom in solving social and economic system problems using human–machine cooperation. He is also interested in conducting research on system methodology, with a special emphasis on Oriental culture and philosophy. Together with Zhu, Gu proposed the Wuli–Shili–Renli system approach.

**Tu Bao Ho** is a professor in the School of Knowledge Science at the Japan Advanced Institute of Science and Technology (JAIST). He received a BTech in applied mathematics in October 1978 from Hanoi University of Technology in Vietnam; an M.S. (DEA) in computer science in 1984 from the University of Paris VI in France; a Ph.D. in computer science in February 1987 from the University of Paris VI; and a habilitation in computer science in October 1998 from the University of Paris IX (Dauphine) in France. His research interests include artificial intelligence, conceptual modeling and knowledge-based systems, machine learning, knowledge discovery and data mining, decision science and knowledge-based decision support systems, pattern recognition and intelligent data analysis, computational science, computational medicine, and biology. He has published approximately 50 journal articles, 200 refereed conference papers, and 15 book chapters. He also has edited some conference proceedings.

**Yoshiteru Nakamori** received a Ph.D. in applied mathematics and physics from Kyoto University in Kyoto, Japan, in 1980. He then served in the Department of Applied Mathematics as faculty of science at Konan University in Kobe, Japan. From September 1984 to December 1985 he stayed at the International Institute for Applied Systems Analysis in Laxenburg, Austria, where he joined the Regional Water Policies Project. He joined the Japan Advanced Institute of Science and Technology in April 1998 as a professor in the School of Knowledge Science. He served as the dean of this school from April 2001 to March 2007. From October 2003 to March 2008 he led a research program on the theory and practice of technology creation based on knowledge science. The goal of this program was to create a world-class center of excellence in (1) theoretical research—with a final target of strategic research and the development of scientific technologies in which knowledge fusion and development in important scientific fields would be studied and then a theory of scientific knowledge creation established; and (2) practical research—as theories were developed, they would be applied in scientific laboratories and approved by feedback from practice. Through repetition of this task, the theory would be improved and the creation of useful scientific technologies promoted. At the same time, graduate students would be trained in this environment and taught to become knowledge coordinators or knowledge creators. Nakamori joined the establishment of the International Society for Knowledge and Systems Sciences in December 2003 and served as president of the society until December 2008.

**Zhongtuo Wang** is a professor in the School of Management at Dalian University of Technology (DUT), head of the Ph.D. systems engineering program, and the director of the Research Center of Knowledge Science and Technology at DUT. He is a member of the Chinese Academy of Engineering. He was the vice president of the Systems Engineering Society of China. In the 1950s, he joined the Department of Electrical Engineering at Dalian University of Technology. As founder of the Department of Control Engineering at DUT, he contributed greatly to the teaching and research works in the field of optimizing control and computer applications. In 1977, he moved to systems engineering. As one of the originators of the Ph.D. program and research works of systems engineering in China and founder of the Institute of Systems Engineering at DUT, he devoted himself to the task of theoretical research in decision analysis, complex adaptive system, and network optimization. As a leader he has organized a great many projects that apply systems engineering methodologies and techniques to Chinese economic and engineering endeavors, including strategic analysis of regional economic development, production planning of petroleum refineries, planning and scheduling of construction projects, and the impact of information technology on management transformation. He also organized the M.S. and Ph.D. programs in systems engineering and management science at DUT. From 1986 to 1988, he worked at the International Institute for

Applied Systems Analysis (IIASA) in Vienna, Austria, as a research scholar and the head of an international collaborative project and is known internationally for his contributions. He has published 10 books and more than 170 papers and reports. He has received two national awards and nine awards from ministries of Chinese government. He currently works in knowledge management and technological innovation.

**Andrzej (Andrew) Piotr Wierzbicki** earned an M.E. in telecommunications and control engineering (1960), a Ph.D. in nonlinear dynamics in control (1964), and a D.S.c. in optimization and decision science (1968). He has worked as a professor at Warsaw University of Technology (WUT) (1960–2004); dean of the Faculty of Electronics at WUT (1975–1978); chair of the Systems and Decision Sciences Program at the International Institute for Applied Systems Analysis in Laxenburg, Austria (1979–1984); member of the State Committee for Scientific Research of the Republic of Poland and the chair of its Commission of Applied Research (1991–1994); director general of the National Institute of Telecommunications in Poland (1996–2004); and research professor at the Japan Advanced Institute of Science and Technology in Nomi, Japan (2004–2007). Beside teaching and lecturing for over 45 years and promoting over 100 master's theses and 20 doctoral dissertations at WUT, he has also lectured in doctoral studies at many Polish and international universities. Wierzbicki has authored more than 200 publications, including 14 books, over 80 articles in scientific journals, and over 100 conference papers; he is also the creator of three granted and industrially applied patents. Current interests include vector optimization, multiple criteria and game theory approaches, negotiation and decision support, issues of information society and knowledge civilization, rational evolutionary theory of intuition, theories of knowledge creation and management, knowledge engineering, and modern history of information technology.

**Zhichang Zhu**'s formal education stopped when he was 16 due to China's Cultural Revolution. Without a high school certificate or prior university degree, he obtained a M.S.c. in information management (1990) and a Ph.D. in management systems and sciences (1995), specializing in marketing, and sponsored by British scholarships. Zhu has been a Maoist Red Guard, farm laborer, shop assistant, lorry driver, corporate manager, assistant to the dean of a business school, software engineer, systems analyst, and information systems and information technology business consultant in China, Singapore, Sri Lanka, and England. Zhu is currently a reader in strategy and management at the University of Hull Business School (HUBS). He has held positions as the director of the HUBS Ph.D. program, a visiting research professor in the School of Knowledge Science at the Japan Advanced Institute of Science and Technology, a visiting research professor in strategy and management at South China Normal University, a visiting research professor in International Business Management at International East–West University

(Honolulu and Los Angeles), a visiting lecturing professor in innovation and entrepreneurship at Friedrich Schiller University (Jena, Germany), a visiting lecturing professor in strategy in emerging markets in the East–West Knowledge Leaders Program (Hawaii), and an external examiner for Ph.D. theses for Cape Town University (South Africa) and Swinburne University of Technology (Australia). Zhu has delivered invited keynote speeches and guest lectures to international conferences, universities, and research institutes in China, Germany, Hong Kong, Indonesia, Ireland, Japan, the Gulf, and the United States as well as in the United Kingdom. Zhu is an editor of the international journals *Systems Research and Behavioral Science* and *International Journal of Knowledge and Systems Science*. He is an organizer of the comparative institutional research project sponsored by the Ford Foundation, the international *Systems East & West* project sponsored by the International Federation for Systems Research, the China–Japan–UK research project in systems and knowledge management sponsored by universities and industries in three countries, and a founding member of the International China Association for Management of Technology. Zhu provides business consultancy for Chinese and British corporations in auto-making, leather goods, animal food, and estate industries, including a *Forbes 500* company. Zhu has researched strategy, decision making, marketing theory, information systems, and knowledge management, all from an institutional, comparative perspective, with over 70 articles published in refereed journals, edited books, and international conference proceedings.

# Contents

# 1

# *Introduction*

**Yoshiteru Nakamori**
*Japan Advanced Institute of Science and Technology, Japan*

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## 1.1 School of Knowledge Science

The School of Knowledge Science at Japan Advanced Institute of Science and Technology (JAIST*) started in April 1998 and is the first of its kind established in the world to take *knowledge* as a target of science. The school was started after the work of Ikujiro Nonaka, first dean of the school and world renowned for his organizational knowledge creation model (Nonaka and Takeuchi, 1995), in which new knowledge is created between explicit and tacit knowledge through a socialization, externalization, combination, and internalization (SECI) spiral:

1. *Socialization* is a process of sharing experiences and thereby creating tacit knowledge such as shared mental models and technical skills.
2. *Externalization* is a process of articulating tacit knowledge into explicit concepts, taking the shape of metaphors, analogies, concepts, hypotheses, or models.
3. *Combination* is a process of linking explicit knowledge to obtain a knowledge system.
4. *Internalization* is a process of embodying explicit knowledge into tacit knowledge. It is closely related to learning by doing.

* JAIST was founded on October 1, 1990, as the first national institute in Japan that consists of graduate schools without undergraduate programs and possesses its own campus and organization for research and education.

This theory is revolutionary because it stresses steps leading to knowledge increase definitely, 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 this school, the founders had to distinguish knowledge from information, which is necessary to explain the structure of the school. Information is knowledge transmitted by, for example, character, sign, or voice or by data arranged to be useful for decision making. Thus, the meaning of *information* can vary from other persons' knowledge to simply collected data. On the other hand, *knowledge* is recognition memorized personally or socially or judgment or a system of judgment that has objective validity. Using the latter definition, people transform data into information and information into knowledge.

The energy that brings about such transformation is called *intelligence.* Intelligence has several meanings, but here we consider computers' ability to judge things automatically or people's ability to understand and learn things. The structure of the school, which includes the following, was constructed in this light:

- *Information science* to develop computers' ability to judge things automatically
- *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, whereas important knowledge in management science is tacit; it is quite difficult to transfer people's knowledge to others with words. This is the reason 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 integrates these fields at the interdisciplinary project level and facilitates 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 areas 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 in extensive technological and social innovations.

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 following three areas in the school:

- 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, epistemology)

## 1.2 Approaches to Knowledge Science

We could count several research fields related to knowledge science (Figure 1.1):

- *Knowledge engineering*: Symbolizing (approximating) experts' knowledge to develop artificial intelligence
- *Knowledge discovery*: Mining a large-scale data set to extract partial rules and adding their meanings based on domain knowledge
- *Knowledge construction*: Simulating complex phenomena based on some hypothesis and adding the meanings to emerged properties based on domain knowledge
- *Knowledge management*: Converting distributed (or tacit) knowledge into shared (or explicit) knowledge and using it effectively

The feature of these fields is the use of computers, expanding traditional information science, which means that these fields use subjective knowledge, indicated by italic letters in Figure 1.1.

Organizational knowledge creation is the key academic factor to establish the School of Knowledge Science; after the SECI spiral, some different spirals

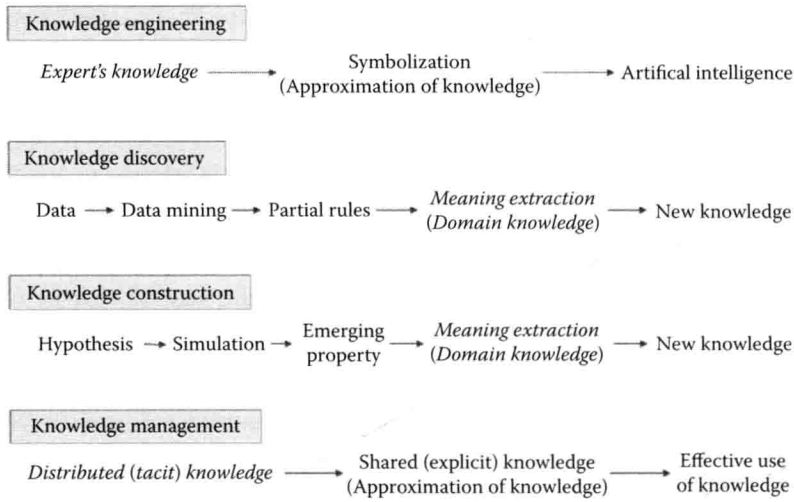


**FIGURE 1.1**
Existing research fields related to knowledge science.

were proposed. While the SECI spiral is a bottom-up type, Gasson (2004) proposed a top-down type model by analyzing possible transitions among the same four nodes (here group knowledge is called shared knowledge and individual knowledge is called distributed knowledge) in the organizational culture of a Western company. Wierzbicki, Zhu, and Nakamori (2006) proposed personal knowledge creation models that correspond to disciplinary knowledge creation. The feature of these models is to use persons directly, beyond information science (Figure 1.2).

However, to solve complex real-life problems we need knowledge synthesis, collecting, and interpreting different types of knowledge from the cognitive-mental front, scientific-actual front, and social-relational front (Figure 1.3).

Nonaka, Toyama, and Konno (2000) called the dynamic context that is shared and redefined in the knowledge creation process *ba*, which refers not just to a physical space but also includes virtual spaces based on the Internet, for instance, and more mental spaces that involve sharing experiences and ideas. They stated that knowledge is not something that can exist independently; it can exist only 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 several disciplines are integrated, we should expand our research into social and technological innovation to foster revitalization projects and collaborative projects with enterprises. For example, suppose that a student participates in a regional environmental project of a certain city. If the main theme is the extent of reductions in the concentration of carbon dioxide and

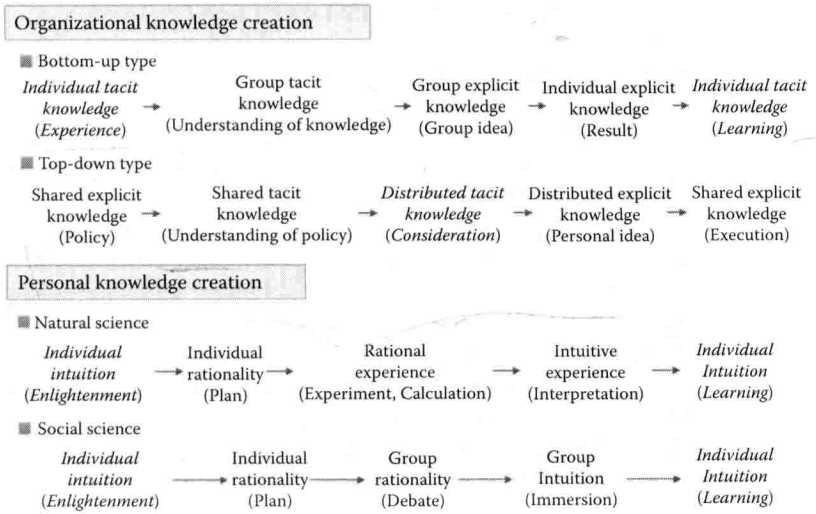


**FIGURE 1.2**
Organizational or personal knowledge creation models.

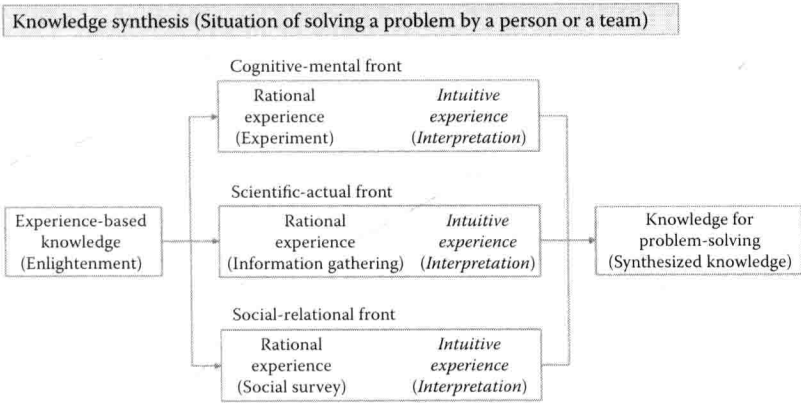


**FIGURE 1.3**
Knowledge synthesis to solve complex real-life problems.

the analysis of economic effects and the secondary theme is converting food residue into ethanol, the student would receive guidance from the School of Materials Science for the secondary theme. In addition, the qualities of a coordinator should 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 is successfully imported and marketed, this will contribute to both the vitalization of the regional economy and the student's growth in international activities.

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 and education into the theory and practices of social and technological innovation.

Consider the following questions while reading this book:

1. Are you treating knowledge in your research?
   a. If yes, what kind of knowledge are you treating?
   b. (Note) You might treat just information, not knowledge.
   c. (Note) There is a critique that one can manage information but cannot manage knowledge.
2. Try to understand what ba is (ba = creative environment).
   a. What kind of ba are you involved in?
   b. (Note) It is said that knowledge can exist only in a form embedded in ba.
   c. (Note) This definition of knowledge is significant when considering its difference from information.
3. Do you think that you are creating knowledge?
   a. If yes, explain your spiral in creating knowledge.
   b. (Note) You can either consider your individual study or your research in your group.
   c. (Note) Remember the definition of knowledge, which is not just information or data.
4. Do you have a confidence that you will become an innovator or a knowledge coordinator?
   a. If yes, explain your style of study to become an innovator or a coordinator.