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KNOWLEDGE SYNTHESIS IN TECHNOLOGY DEVELOPMENT*

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Abstract

This paper introduces a knowledge construction model called the *i*-System for knowledge integration and creation and its relation to the new concept of the Creative Space. The five ontological elements of the *i*-System are *Intelligence*, *Involvement*, *Imagination*, *Intervention*, and *Integration* corresponding to five diverse dimensions of the Creative Space. The paper discusses the meanings and functions of these dimensions in knowledge integration and creation, and presents applications of the *i*-System to technology roadmapping and archiving.

Keywords: Knowledge construction, creative space, technology roadmapping, technology archiving

1. Introduction

Many approaches to knowledge and technology creation have appeared for these 20 years. Their specific feature is that they try to utilize the irrational or arational creative abilities of the human mind, such as tacit knowledge, emotions and instincts, and intuition (Wierzbicki & Nakamori 2006). In management science a novel approach was developed by Nonaka in 1992, with an international publication "Knowledge Creating Company" (Nonaka & Takeuchi 1995). This is the now-renowned "SECI Spiral", with its process-like and algorithmic-like principle of organizational knowledge creation. 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 consists of emotions and intuition.

Historically, the first of such approaches is "Shinayakana Systems Approach" by Sawaragi (Sawaragi & Nakamori 1992), in the field of decision and systems science. Being systemic and influenced by the soft and critical systems

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tradition, it did not specify a process-like, algorithmic recipe for knowledge and technology creation, only a set of principles for systemic problem-solving. To these principles belong: using intuition, keeping an open mind, trying diverse approaches and perspectives, being adaptive and ready to learn from mistakes, and being elastic like a willow but sharp as a sword in short, *Shinayakana* (= flexible and elastic, willowy).

Further development of the "Shinayakana Systems Approach" was given in Nakamori (2000, 2003), in a systemic and process-like approach to knowledge creation called the "Knowledge Pentagram System" or the "*i*-System". True to the *Shinayakana* tradition, there is no algorithmic recipe for how to move between its ontological nodes: all transitions are equally advisable, according to individual needs. Thus, the *i*-System stresses the need to move freely between diverse dimensions of creative space. The *i*-System has several applications such as to development of a knowledge archive system, an evaluation system of research activities and environments, and a fresh food management system. This paper presents its use in technology roadmapping and archiving.

2. Knowledge Construction Models

This section presents the *i*-System for knowledge integration and creation and its relation to the new concept of the Creative Space (Wierzbicki & Nakamori 2006). The five ontological elements of the *i*-System are *Intervention*, *Intelligence*, *Involvement*, *Imagination*, and *Integration* corresponding to five diverse dimensions of the Creative Space. We discuss the meanings and functions of these dimensions in the context of knowledge integration and creation. We also discuss the relation of the *i*-System to "*Shinayakana Systems Approach*". "*Shinayakana*" means soft and hard together − elastic like a willow and sharp as a sword, implying a synthesis between soft and hard systemic approaches.

2.1 Creative Space

Wierzbicki & Nakamori (2006) have shown how we can fruitfully generalize the SECI Spiral from Nonaka & Takeuchi (1995) by adding more nodes in the basic dimensions of the spiral, thus obtaining the concept of Creative Space; this is illustrated in Figure 1. Essentially, the epistemological dimension of SECI Spiral is enriched by splitting tacit knowledge into its two specific parts: emotive knowledge and intuitive knowledge, and the other dimension (called ontological in Nonaka & Takeuchi 1995, and more precisely social in Wierzbicki & Nakamori 2006) is enriched by adding the third level of humanity heritage to the levels of individual and group. This way, a three-by-three matrix is distinguished, indicating nine nodes of Creative Space shown in Figure 1; there are also diverse transitions between these nodes (called in Nonaka & Takeuchi (1995) knowledge *conversions*).

While, for example, the nodes of individual emotions and individual intuition just show more specifically which parts constitute individual tacit knowledge, the consideration of the three nodes of humanity emotive, intuitive, and rational heritage is a very important addition to SECI Spiral: every process of knowledge creation is in fact based on humanity intellectual heritage, called the third world by Popper (1972)

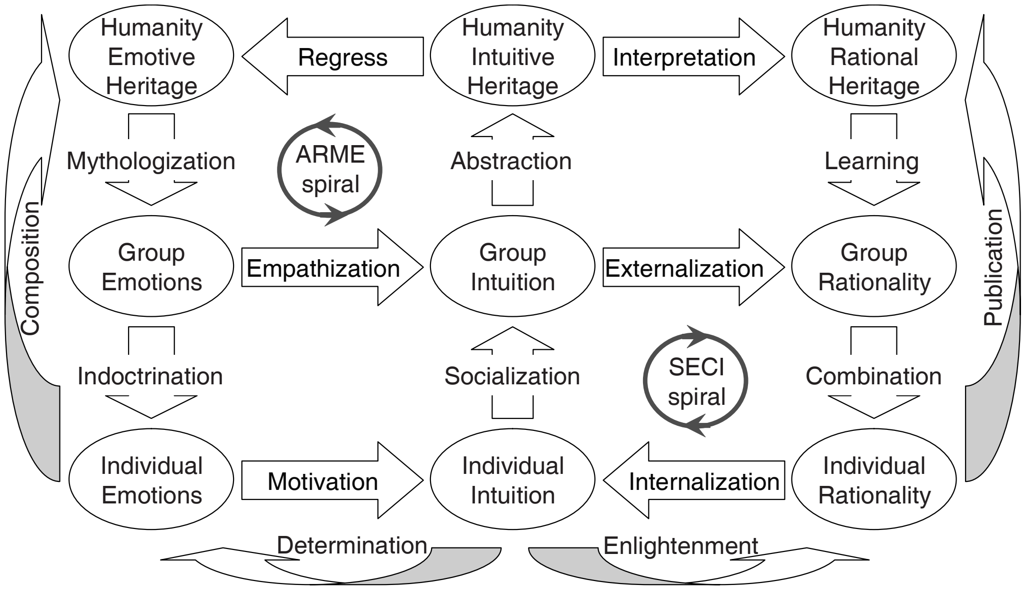

Figure 1 The basic dimensions of creative space (Wierzbicki & Nakamori 2006)

but including rational, intuitive and emotive parts.

In this way new descriptions of creative processes can be obtained. For example, while the four nodes in the lower right-hand corner of Figure 1 represent the known SECI Spiral, the four nodes in the upper left-hand corner of Figure 1 represent another theory of knowledge creation, the Theory of Regress by Motycka (1998), describing the processes of basic knowledge creation in time of a scientific revolution, such as during the creation of quantum theory; this theory can be also represented as a spiral which consists of transitions Abstraction - Regress - Mythologization - Empathisation, hence ARME Spiral; for more detailed description and analysis, see Wierzbicki & Nakamori (2006) and Wierzbicki (2005).

2.2 The *i*-System

However, the Creative Space has certainly more dimensions than just the epistemological and social dimensions used in Figure 1. This is stressed by the *i*-System – see Nakamori (2003); its five ontological elements are *Intervention*, *Intelligence*, *Involvement*, *Imagination*, and *Integration* and they might correspond actually to five diverse dimensions of Creative Space; thus, they stress the need to move freely between more dimensions of this space.

These five ontological elements were originally interpreted as nodes, as illustrated in Figure 2. Because the *i*-System is intended as a synthesis of systemic approaches, *Integration* is, in a sense, its final dimension (in Figure 2 all arrows converge to *Integration* interpreted as a node; links without arrows denote the possibility of impact in both directions). The beginning node is *Intervention*, where problems or issues

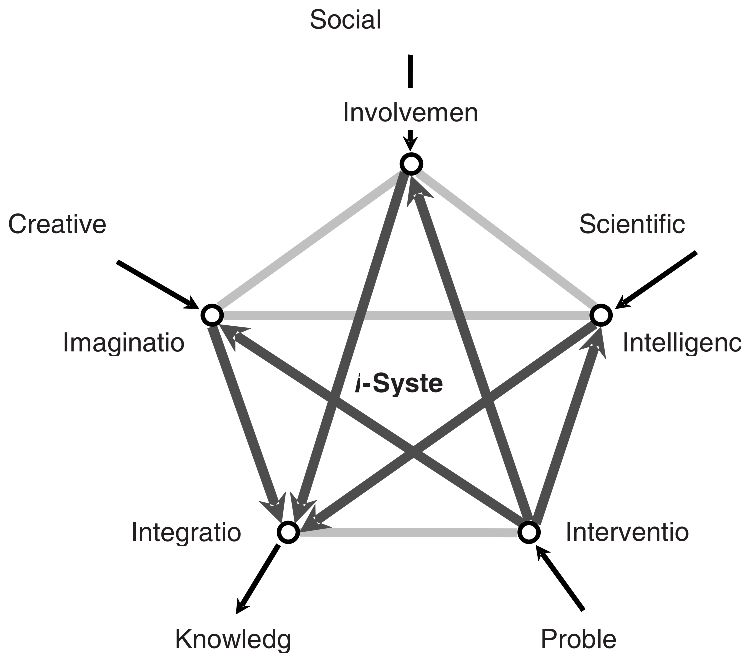

Figure 2 The *i*-System (Nakamori, 2003)

perceived by the individual or the group motivate their further analysis and the entire creative process. The node *Intelligence* corresponds to various types of knowledge, the node *Involvement* represents social aspects. The creative aspects are represented mostly in the node *Imagination*.

Observe, however, that the node *Intelligence* - together with all existing scientific knowledge - corresponds roughly to the basic epistemological dimension (Emotive - Intuitive - Rational knowledge) of Creative Space. The node *Involvement* stresses the social motivation and corresponds roughly to the basic social dimension (Individual - Group - Humanity Heritage) of the Creative Space.

When analyzing these dimensions Wierzbicki & Nakamori (2006) have found that binary logic is inadequate and even rough, three-valued logic barely sufficient for a detailed analysis. For example, it is not only necessary to distinguish between the knowledge on the level of individual, group and humanity heritage; it is also important to distinguish motivation related to the interests of the individual, the group and humanity. While an organization operating in the commercial market rightly stresses the interests of the group of people employed by it (or of its shareholders), educational research activity at universities might be best promoted when stressing the individual interests of students and young researchers; on the other hand, the interests of humanity must be protected when facing the prospect of privatization of basic knowledge. See Figure 3.

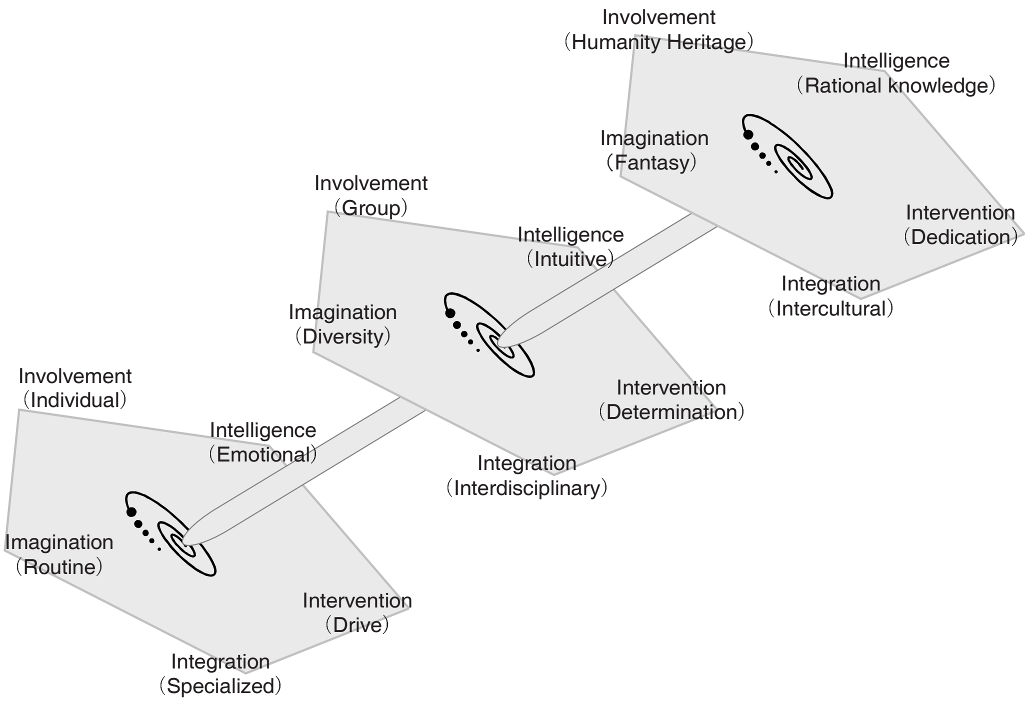

Figure 3 Three levels in *i*-System (combination: $3^5 = 243$)

However, other nodes presented in Figure 2 indicate the need to consider other dimensions of Creative Space, and additional dimensions result in additional complexity. The dimension *Imagination* seems to be an essential element of only individual intuition. All creative processes can be related, on the other hand, to three levels of *Imagination*: *Routine* - *Diversity* - *Fantasy*; we shall discuss the importance of this distinction in the following.

We utilize imagination in diverse degrees depending on the character of a creative process. The lowest level is *Routine* - that involves imagination, but in a standard, well-trained fashion. We are able to use imagination more strongly, to involve an element of *Diversity* - but we must be motivated to do this by professional pride, pure curiosity, monetary rewards etc. Finally, we have also the highest level of imagination, which might be called *Fantasy*. The 20th Century tradition of not speaking about metaphysics (started by Wittgenstein 1922) relegated fantasy to the arts and the emotions. However, fantasy is an essential element of any highly creative process, including the construction of technological devices and systems.

The dimension *Intervention* is difficult to consider separately in Oriental philosophy and culture, with their concepts of unity of mind and body, and unity of man and nature: the will to do something is not considered as a separate phenomenon, it is simply a part of being, and being should be such as not to destroy the unity of man and nature. In a culture seeking consensus and harmony, such an explanation and such principles are sufficient. Occidental or Western culture pays more attention to the problems related to human intervention and will.

Western culture has a long history of philosophic debate of the issues of will and freedom of intervention. The seminal points of this debate start just after the Enlightenment era, in German pre-romanticism, first with the concept of self-realization, then in the *Kritik der praktischen Vernunft* (Kant 1788) with its radical concept of freedom: a man is free in a radical, transcendental sense, self-determining not as a natural being, but as pure moral will: This unity of self-determination, moral life, autonomy and freedom, expressed best by Kant's statement the starlight sky over me and the moral law in me, was exhilarating for his contemporaries and still remains a powerful motivation for the representatives of Western culture.

The concept of will, of freedom to act and intervene, has been for many centuries and still remains one of the central ideas of Western or Occidental culture. Concerning any creative activity, it is clear that the role of motivation, of the will to create new ideas, objects of art, technological devices, etc. is a central condition of success. Without *Drive*, *Determination*, *Dedication* no creative process will be completed. By *Drive* we understand here the basic fact that creativity is one of the most fundamental components of self-realization of man. *Determination* is the concentrated Nietzschean will to overcome obstacles in realizing the creative process. *Dedication* is a conviction that completing a creative process is right in terms of Kantian transcendental moral law.

The dimension of *Integration* in the original *i*-System is a node intended to represent the final stage, the systemic synthesis of the creative process. Thus, in this stage we should use all systemic knowledge; applying systemic concepts to newly created knowledge is certainly the only explicit, rational knowledge tool that can be used in order to achieve integration. Thus, any teaching of creative abilities must include a strong component of systems science.

The apparently simplest is *Specialized Integration*, when the task consists of integrating several elements of knowledge in some specialized field. But even this task can be very difficult as, for example, the task of integrating knowledge about the diverse functions of contemporary computer networks. It becomes more complex when its character is *Interdisciplinary*, as in the case of the analysis of environmental policy models. However, the contemporary trends of globalization result today in new, even more complex challenges related to *Intercultural Integration*, as in the case of integration of diverse theories of knowledge and technology creation. In fact, the *Intercultural Integration* of knowledge might be considered a defining feature of a new interpretation of systems science.

In summary, the knowledge creation system called the Knowledge Pentagram System or the *i*-System is comprised of five elements - dimensions, nodes or subsystems:

1. *Intervention*: Taking action on a problem situation which has not been dealt with before. First we ask: what kind of knowledge is necessary to solve the new

problem? Then the following three subsystems are called on to collect that knowledge.
2. *Intelligence*: Raising our capability to understand and learn things. The necessary data and information are collected, scientifically analyzed, and then a model is built to achieve simulation and optimization.
3. *Imagination*: Raising the interest and passion of ourselves and other people. Sponsoring conferences and gathering people's opinions using techniques like interview surveys.
4. *Involvement*: Creating our own ideas on new or existing things. Complex phenomena are simulated based on partial information, by exploiting information technology.
5. *Integration*: Integrating heterogeneous types of knowledge so they are tightly related. Validating the reliability and correctness of the output from the above three subsystems.

We can interpret these elements variously - either as nodes, or dimensions of Creative Space, or subsystems. In the last interpretation, while the 1st and the 5th subsystems are, in a sense, autonomous, the 2nd, 3rd and 4th subsystems are dependent on others; it is generally difficult for them to complete their missions themselves, and thus we can introduce a lower level system with similar structure to the overall system.

2.3 Shinayakana Systems Approach

Even if the *i*-System stresses that the creative process begins in the *Intervention* dimension or subsystem and ends in the *Integration* dimension or subsystem, it gives no prescription how to move in between. There is no algorithmic recipe how to move between these ontological nodes or dimensions: all transitions are equally advisable, according to individual needs. This is true to the *Shinayakana Systems Approach* tradition that is in a sense further developed by the *i*-System. Thus, for a better understanding of the *i*-System it is useful to comment also on the *Shinayakana Systems Approach*.

The *Shinayakana Systems Approach* is a systemic approach proposed by Sawaragi for several years prior to its publication (Sawaragi & Nakamori 1992). The approach proposes a synthesis, an integration of hard and soft systemic methods, integration from the perspective of Japanese philosophy and culture. In the *Shinayakana Systems Approach*, Sawaragi tried to resolve the controversy between hard and soft systems traditions by using Far East philosophy: both hard and soft sides are necessary, we must use them in harmony and seeking consensus. Most important is the principle of openness to diverse soft systems approaches while preserving the strength and variety of hard systems approaches, the principle of being hard and soft at the same time.

In fact, *Shinayakana* means both soft and hard - elastic like a willow and sharp as a sword. Because of their synthesis of soft systems thinking with Oriental philosophy, the authors of *Shinayakana Systems Approach* did not formulate any spirals, any algorithmic processes, only a general description of principles.

The *i*-System is in fact a continuation of *Shinayakana Systems Approach* with slightly more algorithmic tendency - although, as we already observed, the *i*-System gives no precise prescription how to move between ontological nodes or dimensions, true to the *Shinayakana* tradition.

On the other hand, the *Shinayakana Systems Approach* and the *i*-System give a different way to the synthesis of soft and hard systemic approaches than Critical Systems Methodology (CSM) or Critical Systems Thinking (see, e.g., Jackson 2000). CSM tries to broaden the approach of Soft Systems Methodology (SSM) (Checkland 1981), but preserves the assumption of the superiority of soft systemic approaches made by SSM.

The *Shinayakana Systems Approach* and the *i*-System treat both hard and soft systemic approaches as equally important, following Far Eastern philosophical principles of harmony, integration and methodological simplicity.

3. Sociological Interpretation

Nakamori & Zhu (2004) explored the *i*-System as a (re-)structurationist model for knowledge management (see Figure 4). Viewed through the *i*-System, knowledge is (re-)constructed by actors, who are constrained and enabled by structures that consist of a scientific-actual, a cognitive-mental and a social-relational front, mobilize and realize the agency of themselves and of others that can be differentiated as *intelligence*, *imagination* and *involvement* clusters, engage in rational-inertial, postrational-projective and arational-evaluative actions in pursuing sectional interests.

The exploration in Nakamori & Zhu (2004) intended particularly to unpack the structure, agency and action 'black boxes', investigate the complexity, ambiguity and emergent properties internal to each of them, as well as those implicated in the relationships between.

While structure complexity provides possibilities for innovation, agency complexity allows actors exploit those possibilities in differing ways. Knowing (integrating) and practice (intervening) are seen as constituting each other, from which knowledge is emerging and embodied, over time, 'back' into structures

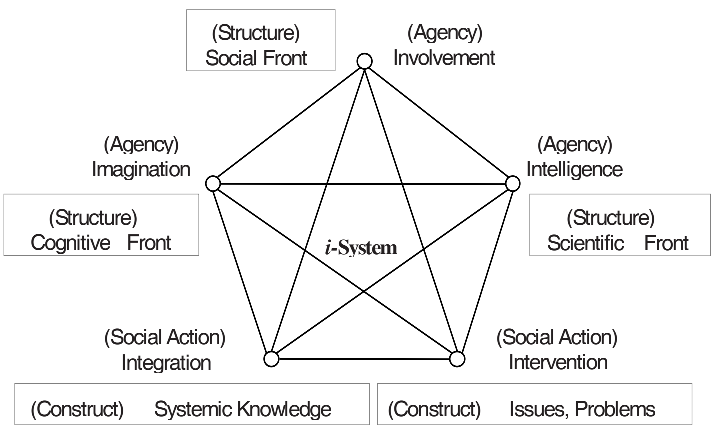

Figure 4 Sociological interpretation of *i*-System

and agency. The exploration drew mainly upon institutionalism, structuration theory, critical realism, actor-network theory as well as Confucianism, Taoism and Zen Buddhism, and was located in the context of technology innovation.

Nakamori & Zhu (2004) unpacked the structure, agency and action black boxes, discussing their internal complexity as well as that implicated in the relationships between them. For this, they drew from, in addition to Western social theories as well as Taoism and Buddhism, the realist Cheng-Zhu and the idealist Lu-Wang schools of neo-Confucianism (see Zhu 1998, 1999, 2000). Their key propositions are summarized in the following:

- Both knowledge-as-construct (the realist Confucianism) and knowing-in-practice (the idealist Confucianism) are indispensable for knowledge construction. Knowledge, stabilized in structure and agency at focal empirical moments, provides actors material, intellectual as well as social capacities and contexts to conduct social action, whereas knowing as that action transforms knowledge, for the better or the worse, which is embodied "back" into structure and agency, over time.
- Both knowledge and ignorance are necessary for effective human action. No destruction, no creation; no forgetting, no knowing; no ignorance, no knowledge. Each contains the seed of becoming the opposite (Zhu 1998). The danger is not knowledge or ignorance per se, but the one-sided searching for simplistic answers for complex problems. Our current education and socialization programs have limits, not because of inefficient, but single-minded. Ignorance, forgetting, innocence and emotion should be in knowledge agendas.
- "Construction" is meant to be practical, temporal and relational. As Wang Yang-ming the 14th-century Confucianist contends, knowledge and action are but one, for purpose, and with consequences (Zhu 2000). Knowledge is not "created" if creation means, as it does in popular "knowledge creation" models, wellordered, linearly progressive, interest-free, politically neutral and intellectually beyond dispute. Rather, knowledge is better seen as always and constantly messy, contextual, provisional, contestable, negotiated, agreed upon, informing, constituting and legitimating.
- The *i*-System brings "the heart" back in knowledge agendas, rather than shy away from it or take it for granted. While knowledge enhances material well-being and spiritual sophistication, at least for some on the globe, it also grants humans awesome power to do all the ugly things to Nature and among human ourselves. Are knowledge, technology and innovation necessarily a good thing? How and who to manage it for good, good for Nature and all, not just the few? These are, to the *i*-System, legitimate and relevant questions in "knowledge management" that is not equivalent to knowledge commodification.
- Rooted in systems sciences, the *i*-System intends to be integrative in spirit. A system to us is a set of components connected such that properties emerging from which cannot be found in components. *Yin and yang* never melt down into a "synthesis", the lost of opposites means death. Hence, integration is about openness, tolerance, interdisciplinary

and intercultural, is an interactive and reciprocal process of perspective-making and -taking (Boland & Tenkasi 1995) and, -sharing and -enriching, not of programming heterogeneity into homogeneity by the magic hand of "system experts".

4. Guidelines on Technology Roadmapping

The *i*-System integrates statistical data and individual persons' fragmentary knowledge, and then creates new knowledge nobody had before. Such knowledge must be tacit, otherwise someone including the system had it; this is a contradiction. Therefore, the system should have a process to convert tacit knowledge into explicit knowledge. This means that the members of the project or relevant people constitute a part of the system. For this characteristics, the *i*-System can be used for constructing technological roadmaps.

4.1 Intervention

Intervention can be understood as a motivational dimension, a drive, or determination, or even dedication to solving a problem. Starting a roadmapping process can be thus thought as an intervention for issues motivating strategic plans. In this dimension, first, initiators of the roadmapping process should have a deep understanding what is the motivation for making the particular roadmap. Second, they should also know what roadmaps and roadmapping are, what advantages roadmapping has, and how to do roadmapping. Third, initiators or coordinators must also consider who should participate in the roadmapping team and motivate them to join, customize a roadmapping process and schedule, and let all participants know the purpose and schedule and their roles in roadmapping.

4.2 Intelligence

Intelligence has two aspects: rational, explicit and intuitive, tacit. It is a duty of the coordinator and of all participants of a roadmapping process to search for relevant explicit information. In this task, the following methods of support could be helpful:

- *Scientific databases:* The access either to disciplinary or to general scientific databases such as *Scopus*, *ScienceDirect*, etc., can be very helpful for researchers to understand what has been done, what is being done, and what should be done.
- *Text mining tools:* The amount of scientific literature increases very fast, thus help in finding relevant explicit information is necessary.
- *Workshops*: in which many experts are involved. Here some selected groupware, such as *Pathmaker*, could be applied to structure and manage discussions among experts.

In fact, the third method involves already some elements of intuitive or tacit knowledge of experts. But an important aspect of good intelligence is individual reflection on and interpretation of the explicit information previously obtained.

4.3 Involvement

Involvement is a social dimension, related to two aspects: societal motivation and consensus building in the group of participants. Roadmapping in a group is a consensus building process. This process might include many researchers, experts, and other stakeholders. There are following important aspects in this dimension.

- *Participation of administrative authorities and coordinators*: If administrative authorities are involved in the coordination of the roadmapping process, then this helps it to proceed smoothly.
- *Customized solutions:* Preparing a template of a solution for the roadmapping process also helps it to proceed smoothly. There are many existing solutions that might serve as templates, such as *T-plan* (Phaal et al. 2001), *Disruptive Technology Rroadmaps* (Kostoff et al. 2004), *Interactive Planning Solutions for personal research roadmaps* (Ma et al 2005), etc.
- *Internet-based groupware*: The use of internet-based groupware can contribute to *Involvement.*

4.4 Imagination

Imagination is needed during entire roadmapping process; it should help to create vision. Participants are encouraged to imagine the purposeful future where should we go and the means how to get there.

- *Graphical presentation tools*: Graphical presentation tools can help people to express and refine their imagination.
- *Simulations:* Simulations can enhance and stimulate imagination, especially concerning complex dynamic processes.
- *Critical debate*: This is probably the most fundamental way of promoting imagination.
- *Brainstorming*: Brainstorming is, in a sense, a counterpart of critical debate; it encourages people to generate and express diverse, even fantastic ideas, and is directly related to imagination.
- *Idealized design*: Idealized design is a unique and essential feature of *Interactive Planning* (Ackoff 1974) which is regarded as a basic method for solving creative problems.

4.5 Integration

Integration must be applied several times during roadmapping, at least when making a first-cut, refined, and the final version of roadmap. Integration includes all knowledge of the other four dimensions, thus is interdisciplinary and systemic.

Diverse rational systemic approaches, such as *Analytical Hierarchy Process* (AHP) (Saaty 1980) and *Meta-Synthesis Approach* (Gu & Tang 2005), might be helpful. However, in order to be creative and visionary, integration cannot rely only on rational, explicit knowledge, must rely on preverbal, intuitive and emotional knowledge. Therefore, software with a heuristic interface and graphical representation tools are essential for help in this dimension.

For example, the number of nodes and links in a roadmap might be large, difficult to master by an unaided human brain. A properly chosen perspective of graphical representation of the roadmap might be thus essential. In order to choose such perspective, a heuristic interface can be applied to infer the preferred features of graphical roadmaps.

5. Application to Technology Archiving

This section presents an application of the *i*-System to technology archiving for a traditional craft industry in Japan. The results of this study indicated that the *i*-System is useful for passing down a rich variety of knowledge of technical development to future generations, and thereby it would support future research and development.

5.1 Knowledge Collection

Besides contribution to regional economy, traditional craft industries have a high cultural value, as they involve techniques that are unique to the regions. The annual production of traditional crafts in Japan was about 200 billion JPY according to the statistics in 2004. However, in the 1980s, it had maintained a value of about 500 billion JPY; in a period of 20 years the production decreased by half.

The production of traditional crafts in Ishikawa Prefecture, where Japan Advanced Institute of Science and Technology is located, has been decreasing every year as well. While the traditional craft industry continues to be in a slump, there are signs of a trend towards preserving works with highly artistic value in the form of digital data. But up until now there has not been much research on preservation of technical innovations in the traditional craft industry. Also, there is no database system for distributing knowledge to the technology developers who support the traditional craft industry behind the scenes.

The traditional craft industry treated in this study is Ishikawa Prefecture's Kutani-ware (ceramics) industry. Ishikawa Prefecture has the Kutani-ware Research Center, a public organization that specializes in giving technical support to the Kutani-ware industry. This center keeps precise reports on technical development, which helps us to collect objective knowledge. In addition, we interviewed technical developers to collect subjective or even implicit knowledge, following the idea of the *i*-System, which limits our survey to techniques developed in these 30 to 40 years because it is difficult to interview already retired developers.

The *i*-System is a methodology for synthesizing, integrating and creating knowledge, which integrates the structure-agency-action paradigm of the West and the dialectic thinking of the East. It treats knowledge in the fronts of cognitive-mental, social-relational and scientific-actual, according to the sociological interpretation.

- *Scientific-actual front*: Technical innovations that were carried out in the Kutani-ware industry were investigated. Business reports published by the Kutani-ware Research Center were used as the main source of information.
- *Social-relational front*: To obtain knowledge about individual technical innovations, previous research and case examples were investigated through the use of literature and interviews with technical developers. The relationship with social and cultural background was mainly focused on in this investigation.
- *Cognitive-mental front*: People who had been involved in technical development for many years were given a detailed interview. They talked about what they had focused on while engaged in technical development, and shared their ideas and thoughts. This enabled us to collect implicit knowledge required to carry out technical innovations.

The subjects of the survey were eight people involved with technical development in the Kutani-ware industry, who belonged to public organizations in Ishikawa Prefecture. The interview started with basic, easy questions pertaining to the person's personal history (number of years of work experience, job description, area of specialization), the trigger for starting the research, the production area's needs in terms of research, information on the production area and the flow of the research. It continued with questions that gradually focused on the essence of the research (ways of solving problems that arise, the situation in terms of collaborators and cooperating organizations, the influence of research results on the production area, and thoughts about the research and changes in feeling at various stages). Questions tailored to each research project were added to these basic questions.

After being transcribed, the interview data was classified and organized according to the *i*-System. As for the specific method of organization, the time-line for the technology development process was set as

1. research trigger and background,
2. study,
3. research into practical applications,
4. commercialization, and
5. improvement.

The collected data for each stage was classified into *Intervention, Imagination, Involvement, Intelligence* and *Integration*. To facilitate classification and organization, we used expressions that were as specific as possible as shown in Figure 5.

5.2 Knowledge Archiving

Due to space limitations the development of translucent porcelain is only partially reported on in this paper. A brief summary of knowledge we collected based on the *i*-System is shown in Figures 6, 7, 8, 9, and 10.

Gathering and organizing information and knowledge pertaining to the Kutani-ware industry based on the *i*-System enabled us to find out matters that were previously known only to people involved with technical innovation. Such information includes cultural and economic conditions, research processes, cooperation with companies in the production area and public organizations, flashes of inspiration that led to the solution of problems, changes in thoughts and feelings about the research being carried out, etc.

Combining such information with existing information we obtained from research reports makes it possible to gain a deeper understanding of past technical innovations, and will undoubtedly contribute to future technical development. Thus, by organizing information and knowledge according to the *i*-System, it is possible to support research and development activities.

6. Conclusion

This paper introduced the *i*-System for knowledge integration and creation and its relation to the new concept of the Creative Space. Its five ontological elements are *Intervention*, *Intelligence*, *Involvement*, *Imagination*, and *Integration* corresponding to five diverse dimensions of the Creative Space. We discussed the meanings and functions of these dimensions in knowledge integration and creation. We also discussed the relation of the *i*-System to "*Shinayakana Systems Approach*".

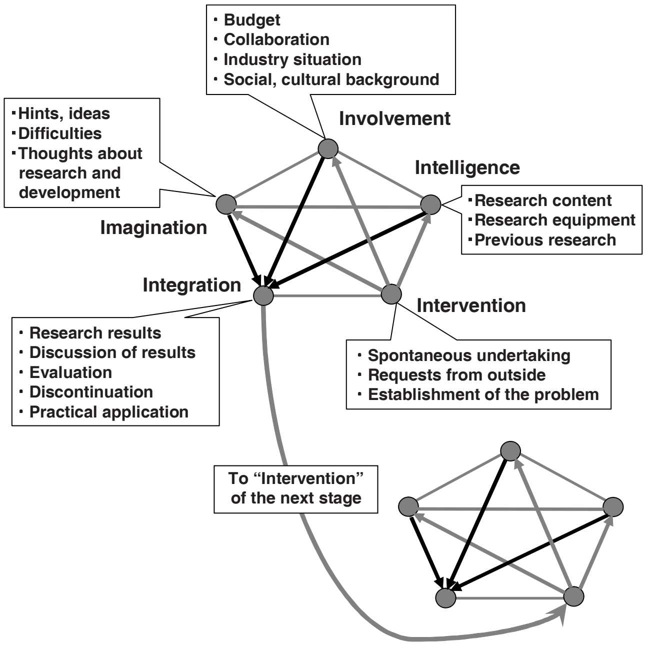

Figure 5 Specific expressions used for interview

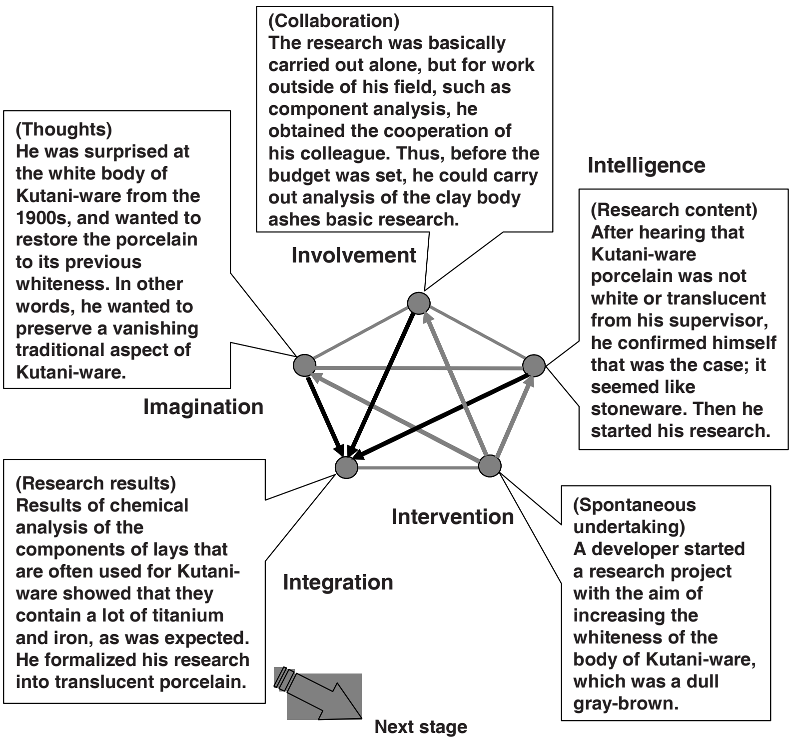

Figure 6 Trigger for development of translucent porcelain

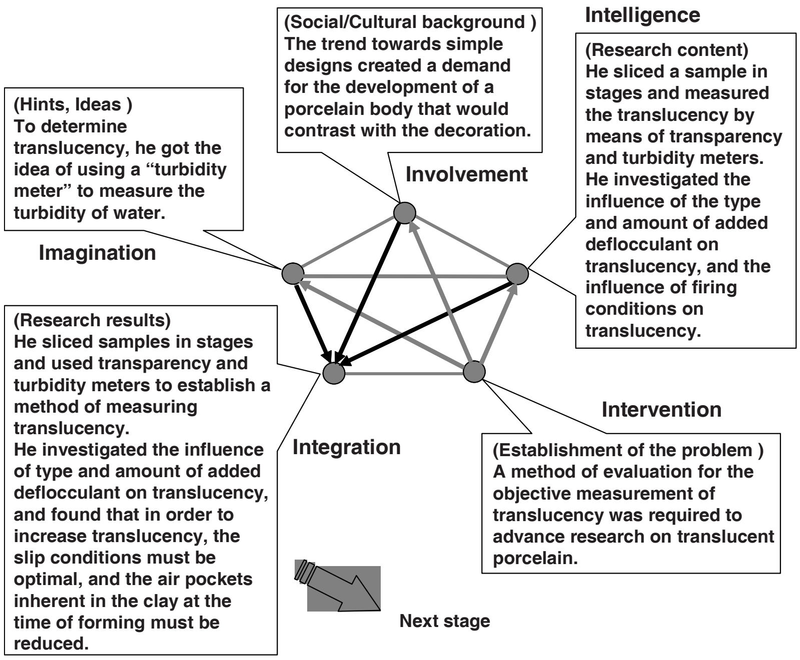

Figure 7 Research and development of translucent porcelain (1)

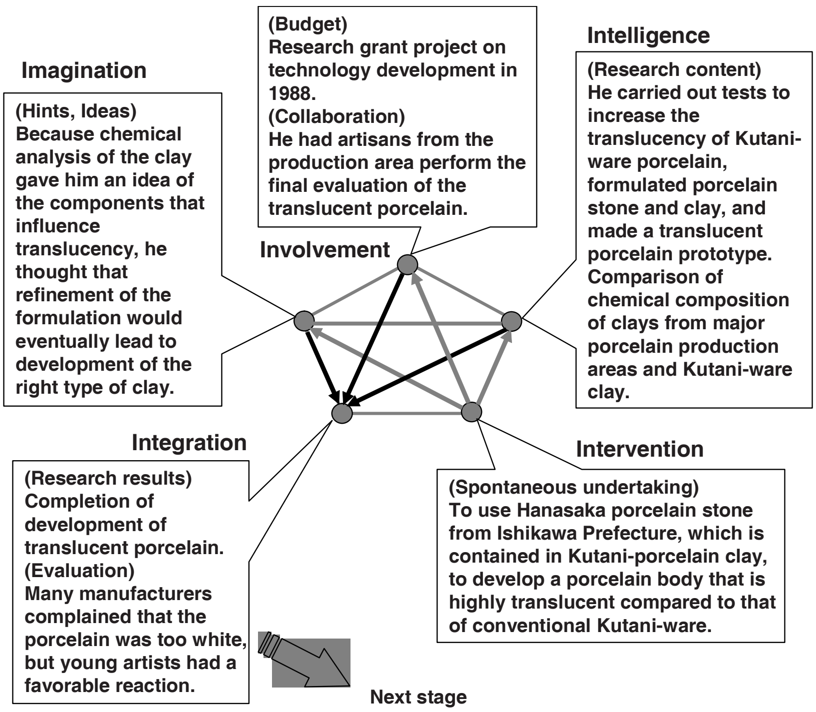

Figure 8 Research and development of translucent porcelain (2)

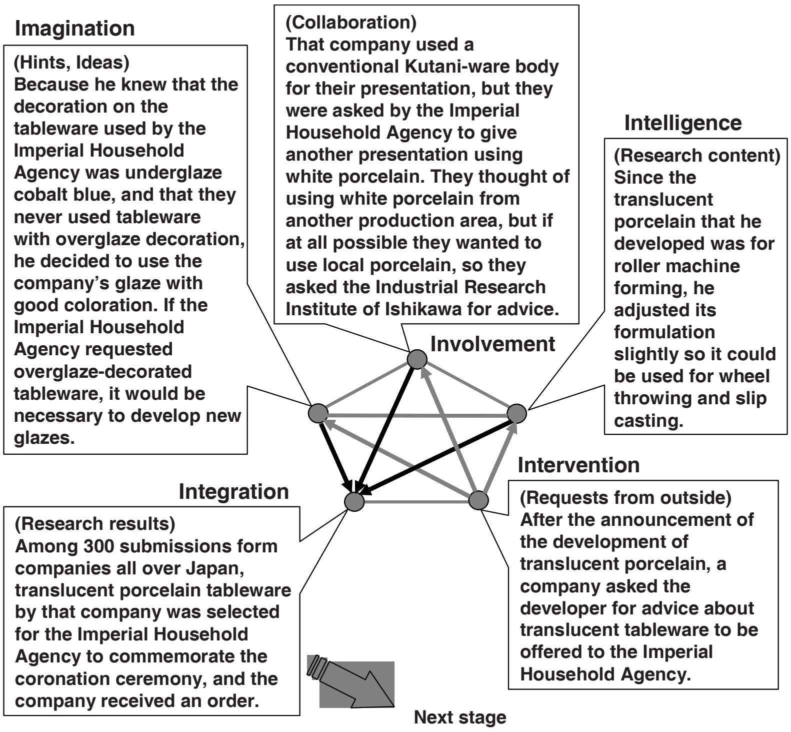

Figure 9 Research into practical applications for translucent porcelain

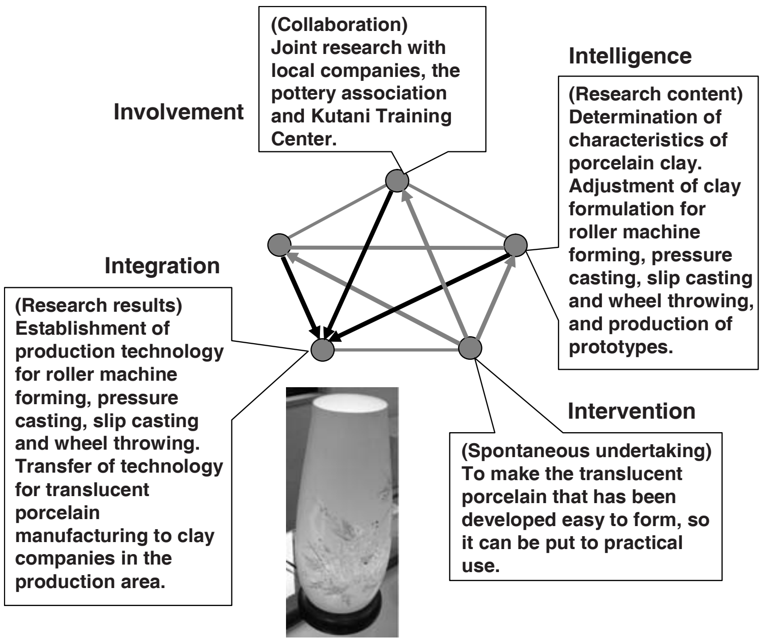

Figure 10 Commercialization of translucent porcelain

The *i*-System can be called a knowledge creating system. The system integrates statistical data and individual persons' fragmentary knowledge, and then creates new knowledge nobody had before. Such knowledge must be tacit, otherwise someone including the system had it; this is a contradiction. Therefore, the system should have a process to convert tacit knowledge into explicit knowledge. This means that the members of the project or relevant people constitute a part of the system. For this characteristics, the *i*-System can be used for constructing technological roadmaps.

The paper also considered the problem of passing down to future generations information about how the traditional craft industry responded to and developed technology to keep up with changes in the times, which is a crucial issue for the recovery of the traditional craft industry. We applied the *i*-System to this issue, and tried to gather and organize information and knowledge about technical innovation in the Kutani-ware industry. In so doing, we found that compared to methods of preservation and passing down of information such as the use of existing research reports, our method made it easy to understand the backgrounds and research processes leading up to research projects, and will possibly support future research and development activities.

The justification and testing of interdisciplinary or philosophical theories of knowledge creation such as the *i*-System is a challenging future problem. We now observe the divergent development of the episteme (the way of constructing and justifying knowledge) of three cultural spheres: hard and natural sciences, technology, and social sciences and humanities. Even if interdisciplinary and philosophical theories have many aspects related either to social sciences, or to hard and natural sciences, they cannot be tested today from the perspective of only one scientific episteme, because contemporary knowledge creation often concerns technology, elements of technological episteme should be also included in the testing. We should establish an integrated episteme for the needs of the era of knowledge civilization.

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