

# Design Methodology for Research and Development Strategy

Realizing a Sustainable Society —————

Hiroyuki Yoshikawa

Center for Research and Development Strategy  
Japan Science and Technology Agency

**Design Methodology for Research  
and Development Strategy**  
— Realising a Sustainable Society —

**Hiroyuki Yoshikawa**

Center for Research and Development Strategy  
Japan Science and Technology Agency

## Preface

The mission of the Center for Research and Development Strategy (CRDS) is to propose research development strategies from a national perspective [1]. Going beyond research and development, the target of this strategy is research that contributes to society through the results. Research as the basis of and at the same time the driver of innovation is especially important. There are, however, many different varieties of contribution to society or innovation that research brings about: some research outcomes passively create unexpected benefit over the long term, while some research is intended to solve current issues. Consequently, the research targeted by the CRDS's strategic proposal is diverse and expansive.

In this book, to provide an initial understanding of the strategic proposal, the role of scientists is described assuming that the relationship of society with science and technology is one of crucial factors for sustainable evolution. Alongside, modern scientific and technological knowledge and the characteristics of its influence on society are presented. Scientists can be thought of as being divided into observing scientists (analytical science) and designing scientists (design science). Their roles are located in the continuous information cycle loop that includes science as well as nature and society. The problematic characteristics of modern scientific knowledge are a division of holistic indigenous knowledge into narrow academic disciplines, an inclination towards pursuing particular cases of immutable existence, an undeveloped holistic observation, and the current immaturity of designing theories. Considering these characteristics, we must develop relevant means to cope with the flood of artefacts and new threats to sustainability.

Based on the concept of science for sustainable evolution called "sustainability science", we consider here a decision policy for research and development strategy that compensates for the weakness in present scientific knowledge. This decision policy advances actual science and technology research and development through the integration of disciplines and collaboration among roles. First, scientists discover the social wishes through holistic observation. Then, they analyse the discovered wishes within functional description as detailed as possible. On the other hand, minimum networks of scientific disciplines which may exert effective functionality in society are composed. Then, the detailed functional description which represents a social wish can encounter a minimum network of scientific disciplines. This is the basic framework of research strategy which accommodates the issue oriented innovation. Practical manuals for this method are not yet established; however, while strategy proposal is being pursued through the afore-mentioned processes at CRDS, measures to create an effective strategy proposal must be made certain.

The following text represents the English translation of the outline of the Japanese version published in June 2010.

Hiroyuki Yoshikawa, February 2012

Director-General,  
Center for Research and Development Strategy (CRDS)  
Japan Science and Technology Agency (JST)

# Contents

## Preface

|     |  |    |
|-----|--|----|
| 1   | The Role of Scientists in Sustainable Evolution .....                            | 1  |
| 2   | Structure of Scientific Knowledge .....  | 10 |
| 2.1 | Characteristics of modern scientific knowledge<br>divided into disciplines ..... | 10 |
| 2.2 | Tasks in the relationship of knowledge disciplines .....                         | 24 |
| 3   | Social Wishes — Analysis of Social Wishes .....                                  | 33 |
| 4   | From Elaboration of Social Wish to Encounter .....                               | 39 |
| 4.1 | Problem statement .....  | 39 |
| 4.2 | Several thought experiments .....  | 45 |
| 4.3 | Importance of strategy design<br>as the first step in research .....             | 51 |
| 4.4 | An example of elaboration of social wish .....                                   | 56 |
| 5   | Structured Panoramic View .....  | 68 |
| 6   | Research Funding Systems .....   | 88 |
| 6.1 | Abandoning the linear model system .....   | 88 |
| 6.2 | Alleviating dissolution of the research community .....                          | 93 |
|     | References .....   | 96 |

# The Role of Scientists in Sustainable Evolution

The role of actors, society and nature, observing scientists and designing scientists is considered in regard to the information-cycle loop that makes sustainable evolution possible. Observing scientists investigate the situation of society and nature by research. Observation here does not refer to observing the individual effects or influences on society and nature by the actions of separate actors, but rather it refers to a "holistic observation" targeting multiple relations among effects and influences. Designing scientists receive the results of observation by observing scientists and design various technologies or methods for actions which would lead society and nature toward sustainability. Then they propose them to society. As it is necessary for this research not only to apply the results of the basic research by observing scientists (they are usually called basic researchers) but also to create a new kind of knowledge (sustainability science), design scientists become a new type of basic researcher in the truest sense of the word. Actors in society select proposals and actually influence society and nature by their actions. This influence is again holistically observed by the observing scientists and the loop is thus completed.

In the 1972 Club of Rome report "The Limits to Growth" [2], Meadows et al. clearly showed that with focus on human population growth, exponential increases of various factors impose a strict limit on all kinds of growth. Yet, before this situation started to appear in reality, the concept of sustainable development was defined in the 1987 UN General Assembly report "Our Common Future" [3], and the major role to be played by the scientific community was subsequently pointed out. The scientific community acknowledged this and adopted the "Declaration on Science and the Use of Scientific Knowledge" (Science for knowledge, knowledge for progress; Science for peace; Science for development; Science in society and science for society) at the 1999 World Conference on Science in Budapest and the 26th International Council of Scientific Unions General Assembly in Cairo. These conferences can be seen as dialogues between society and the scientific community from the 1970s to the 1990s, which Lubchenco [4] pointed out the importance of and coined the "New Contract" between society and science. As seen in Figure 1, this contract forms a loop. In her opinion, the contract is not a theoretical construct, but because at present basic research is actually carried out with national funding paid for by the

general population, the results of every research task must answer the wishes of society. Therefore, money delivered to researchers in the form of research funds bears the wishes of society as a message. This of course does not imply all research has to be of immediate use to society. As the present time marks an attainment of the limits of sustainability, new knowledge targeting tasks not recognized in the past will be necessary and it will be created only by basic research in the truest sense of the word. The new knowledge brings forth more new knowledge, which in turn becomes the basis for the birth of even newer knowledge. Its application provides the basis for actions targeting sustainability. It should be stressed here that such basic research which is different from that in traditional sense is crucially looked for, in order to establish a useful knowledge system which is called sustainability science.

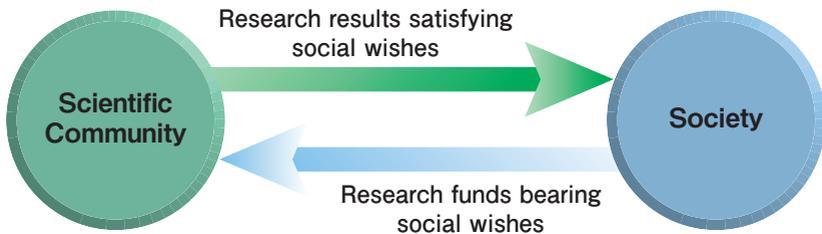


Figure 1 Contract between science and society

Under the claim "basic research in the truest sense", we need special consideration when we select or decide the research subjects as candidates for research fund which encourages innovations for sustainability. Probably, new research subjects such that were not targeted in existing scientific fields should be made the targets in the case of sustainability science. However, if such target cannot be predicted, there may be no relevant method for proper decision of these subjects. Moreover, the results of such research are requested to practically contribute to society which has less experience about sustainability. Society, including general

public, government, industry, and even science community, give unanimous expression loudly that green and life innovations are essential for improving sustainability. But definitions of green and life are ambiguous [5]. These innovations are, as stated elsewhere [6], innovations under some constraints that they should not violate sustainability. What we need in this innovation is deliberate uses of elementary knowledge each of which should be checked not to be harmful when the innovation operates in society. This process will ask scientists new methods, and challenge them to be creative. Creating these methods is the task of the Center for Research and Development Strategy (CRDS) and considerations on this topic are stated in the chapters below.

Before going into the detail of these considerations, it will be stated here what are the basic requests to researchers. Researchers can uncover the requests by participating in the loop which is made of society and scientific community as shown in Figure 2. The interaction in Figure 1 is referred to as a dialogue between society and science, but there is no specific method provided for the dialogue. Lubchenco expressed that the readiness of scientists will be essential together with the role of scientific academies for the realization of the dialogue. Here, we shall start with thinking from the standpoint of CRDS which is engaged in designing research subjects.

There are various kinds of people in society, and sometimes they appeal their requests openly or loudly, but in other cases they are reticent. Therefore we cannot expect that the scientific community is able to receive the people' requests completely or coherently. Sometimes we see visible global requests through the United Nations, but they are only a part of all. Therefore, it is recommended that scientists identify such requests through their own observation of the situation of society and nature.

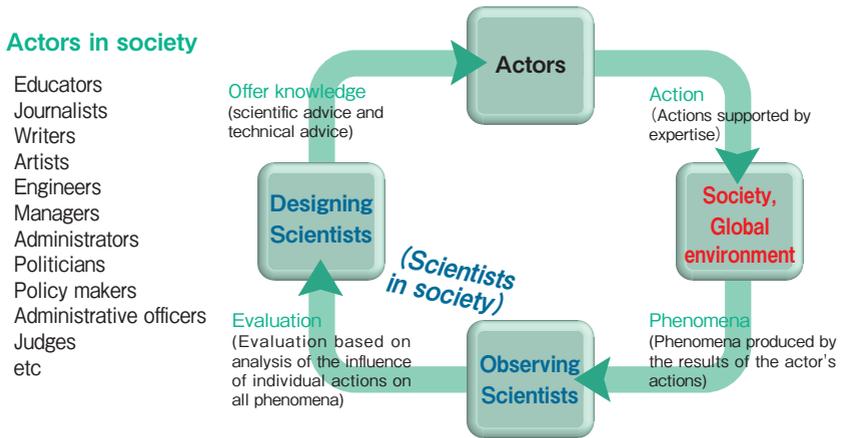


Figure 2 The role of scientists in sustainable evolution

This identification is performed by the observing scientists through their research. Scientists then prepare proposals to society in answer to the identified requests. This is done by the designing scientists. The actors in society who receive the proposals from the designing scientists transform them into action plans relevant to their own special missions. Actors then execute those plans in society and nature. There are various actors who are qualified or specialized by their specialities in society, such as politicians, legislators, policy makers, administrators, lawyers, educators, medical doctors, engineers, industrialists, business people, artists, novelists, as specialists or practitioners, and sometime we may consider the general public as actors. Executions by those actors cause some effects on society and nature, which remain after the executions, thus changing society and nature. The observing scientists again observe these changes. Thus, actors, society (and nature), observing scientists and designing scientists create a loop that forms an information cycle which is the basic structure to realise the aforementioned contract.

This loop is similar to the structures found in the evolution of living things and language. It can also be seen as possessing a similar structure to the evolution of industrial goods, and the comparison with the evolution of language can be represented as shown in Figure 3. The upper figure of Figure 3 shows the evolution of language which models the famous explanation by F. de Saussure about the evolutionary growth of language. The lower figure shows an evolutionary growth of industrial products analogous to language. The latter includes not only the flow of information but also material. Practically, industrial goods are conceptualised by sales specialists following to market survey (similar to observing scientists), and then a design of product is proposed by designers (design scientists) and production departments (actors) manufacture a product and offer them to the market in society. The market accepts or rejects them according to the social evaluation, which is called market mechanism. This cycle allows the product to progress in an evolutionary manner. However, attention has to be paid to the differences with Figure 4 which shows the material flow. While Figure 4 is a famous diagram of the Industrial Dynamics used by Meadows et al. [7] to estimate the limit of material in future, Figure 3 shows a flow of material coupled with that of information which is the social value of products, thus showing the evolution of goods which does not appear in Figure 4. The details are discussed further in Chapters 3 and 4: the idea is that this loop is a necessary condition for bringing sustainability-oriented evolution of society and nature. The industrial goods in Figure 3 are used as an example. In this case, the loop formed by manufacturing enterprise and the market is a necessary condition for product evolution, but it is not sufficient for sustainable evolution because of reasons explained below.

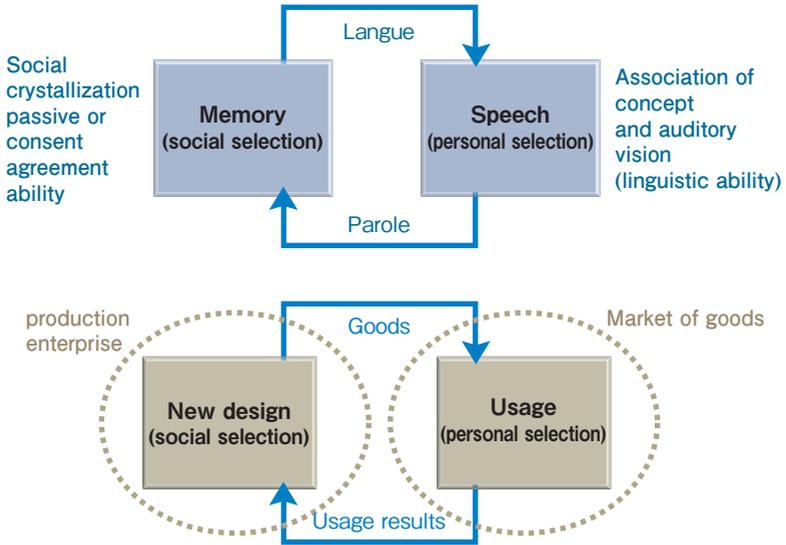
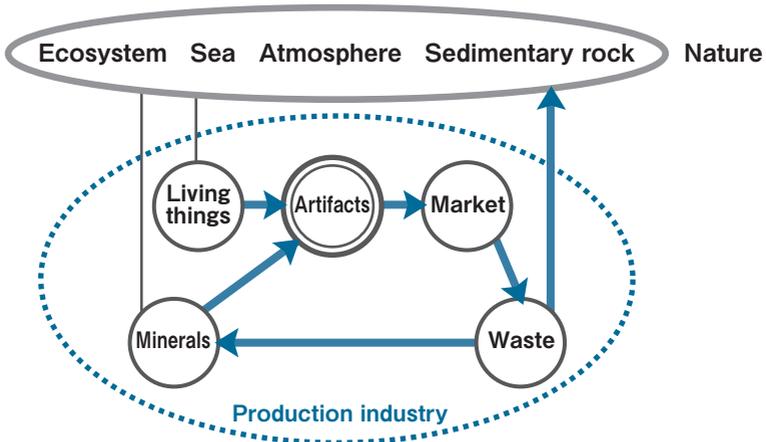


Figure 3 Top: Creation and evolution of language by the information cycle  
 Bottom: Evolution of industrial goods by the information cycle



The material flow can be displayed accurately, fixed quantity evaluation is possible and it is an important research subject. However, in this work, the cycle of information affecting human actions is discussed, and it is necessary to pay attention to the fact that the loop is drawn from a viewpoint differing from above figure.

Figure 4 Material flow accompanying production

Traditionally, industrial goods are released to market as incrementally devised new products. Products presented to the market then receive an accepting or rejecting judgment. This process consists of each product individually being the object of presentation and judgment, and groups of products are not the object of this process, observation and actions as seen in the information cycle of Figure 3. Consequently, individual products can be developed by incremental actions and incremental observation. This process is the standard product development process and can be referred to as the evolutionary process that guarantees the improvement of each individual product. However, this process does not guarantee the improvement of the whole of society that this product is a part of. In other words, it is unclear if this process contributes to the sustainable evolution of society as a whole.

To guarantee holistic improvement, a different method is necessary. This is thought only to be possible with "holistic observation". The problem is, this holistic observation cannot be achieved by observing individual changes separately. Changes occurring in society and nature, be it a phenomenon, event or action, cannot realistically be observed at the same time as they occur.

Consequently, even with such holistic observation, the practical act of observation has to target individual objects. Yet, holistic understanding cannot be achieved by the simple accumulation of discrete observations. Therefore, it is necessary for each observation action to target the relationship between two or more objects in order to make holistic observation possible. For example, observing the effect of enforcing a single law on society is a separate observation. Observing the effect of a different law is yet another separate observation. However, merely summing these two observations does not constitute a component of holistic observation. Rather, it is necessary in this case to observe the interactive effects of the enforcement of these two laws, and the observation of this interaction becomes the smallest component of holistic observation.

In this example, appropriateness of the interaction is judged by logical consistency between two laws, harmony in the place of actual enforcement and praise to enable people to respect both laws at the same time without contradictions. If these are achieved, the observation results lead to a positive evaluation. If, on the other hand, there are obstacles to consistency, harmony and praise, even if each law is respectively acceptable, the holistic observation leads to a negative evaluation and a request for reform of these laws.

| Action<br>Observation | Incremental            | Holistic                |
|-----------------------|------------------------|-------------------------|
| Incremental           | Modern science         | Conservation technology |
| Holistic*             | Sustainability science | Historicism             |

Incremental actions depending on incremental observation: modern science (evolution not guaranteeing sustainability)

Holistic actions depending on incremental observation: Conservation technology (continuous stability without evolution)

Incremental actions depending on holistic observation: Sustainability science (sustainable evolution)

Holistic actions depending on holistic observation: Historicism (downfall without evolution)

\*Total(holistic): what Saussure called synchronic and  
J.Piaget called equilibrium schema

Table 1 Categorization of observation and action

This interaction is not limited to the enforcement of law, but is something present in all consequences of actions that form the basis of scientific knowledge, like release of new products to the market or the implementation of new medical treatments. A huge subject to be investigated is waiting here, and it is necessary to begin with the challenging development of an observation method for the interaction of actions. This is a subject related to research methods, but it is not just an empty dream. There already exists an example where total observation covering multiple scientific disciplines was realised. This example is the process of the world cooperation targeting the global warming. While we may learn important knowledge from this process, analysis of this process will be done in Chapter 5 (Structured Panoramic View).

The modes of change in nature and society in accordance with the loop in which scientists participate are categorized in Table 1. Even if such a loop develops, there are still limiting conditions to realise a preferable evolution. They are necessary observations and actions which do not violate rules derived from sustainability science in order to accomplish innovations (green innovation and life innovation) that are to form the sustainable society. This is one of the important frameworks or limiting conditions for devising research proposals relevant to sustainability. Today, the scientific disciplines working under this limiting condition are recognised as being on the way of development, as shown in Table 2. The basis of these emerging disciplines is clearly different from that of traditionally established academic disciplines. This will be the topic of Chapter 2 (The Structure of Academic Disciplines).

| <b>Emerging disciplines</b>   | <b>Related disciplines</b>                     | <b>Desirable disciplines</b>     |
|---|--|----------------------------------|
| Climate change science  | Evolutionary theory<br>(paleontology, geology) | Synthesiology                    |
| Biodiversity science  | Theory of language<br>creation                 | Science of<br>information cycles |
| Material cycle science  | Anthropology,<br>ethnology, sociology          | Science of<br>connectedness      |
| Welfare economics   | Cultural anthropology                          | Theory of<br>social technology   |
| Education for sustainable<br>development                                    | Program science                                | 4-dimensional lens               |
| Life technologies<br>(life science + life ethics)                           | Systems science                                |                                  |
| Artifactual engineering<br>(engineering disciplines +<br>technology ethics) | Informatics                                    |                                  |
| Science of social wishes  |  |                                  |

Table 2 The science of sustainability  
(holistic observation and incremental action)

## 2.1 Characteristics of modern scientific knowledge divided into disciplines

Modern science has produced many disciplines and efficiently accumulated knowledge. Each discipline is complete and systematic but the relationship between disciplines is not systematic because their origins are intuitive. We should recognise that knowledge about the connection between disciplines is poor. Thus, the complex relationship between the artefacts produced by using the knowledge of individual disciplines has created a new threat to the sustainability of nature and society.

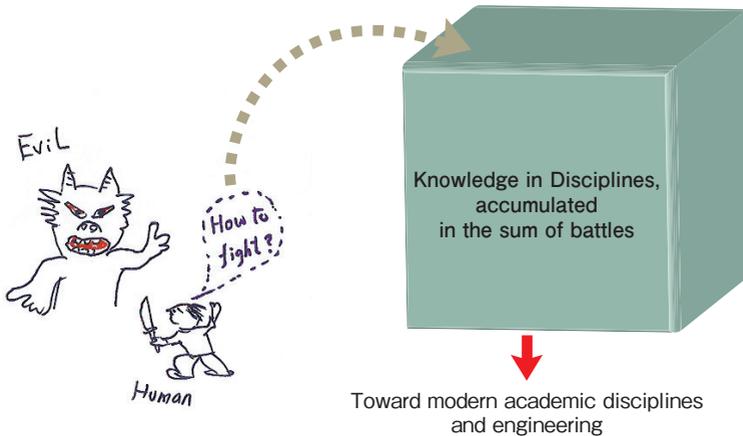
Academic disciplines are extremely diverse. There are several causes for this diversity: knowledge of facts, usage and meaning that was once unified as indigenous knowledge is now split and abstracted, abstraction levels are various, as are specific interests. We define two categories of disciplines: first is what people call just "discipline", which targets things that exist without being created purposefully by humans, and the second is "preliminary discipline", which targets artefacts. The bias of the knowledge in these "disciplines" toward factual knowledge is a characteristic of modern scientific knowledge.

When talking about "Basic research for society", the first question to ask is what society wishes from science. This topic will be discussed in detail in Chapter 4. In the following, we take a general view of the present situation of academia which works aiming at answering the wishes.

What society wishes from science is related to sustaining and improving society (or nature), and an item of wish, on the wish list, does not necessarily find a relevant single discipline within which the wish is given a satisfactory solution. We must recognise that no wish can be answered by the knowledge of a single specific academic discipline. This agrees with our experience that an innovation has to be the product of cooperation between scientists of multiple professional disciplines [8]. Consequently, the cooperation of researchers from multiple disciplines is indispensable in

basic research for society that targets innovations. However, to understand what form this cooperation should take, it is necessary to understand the structure of scientific knowledge divided into disciplines.

This discussion will start with the assumption that the human actions leading to degradation of the global environment are related to the structure of scientific knowledge held by humankind. This discussion targets not only the insufficient knowledge of how to counter this degradation, but also the problem that the main causes leading to the degradation are hiding within modern knowledge. It is necessary to understand this when thinking about deciding the direction of future research.



*The motivation of medieval knowledge creation was the battle against evil*

Figure 5 Birth of disciplines of knowledge

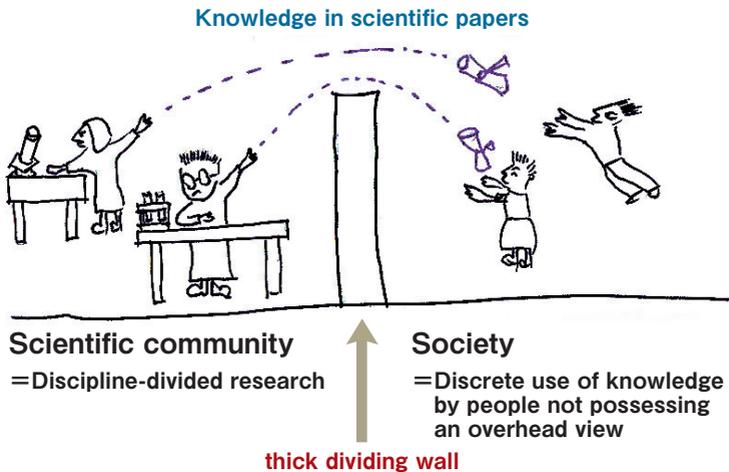
One could well say that modern scientific knowledge has its origins in humankind's battles against evils. Humankind is a weak species when we take views of strength and arms as sharp nails and strong fangs. But it has always won victories over enemies which attacked it owing to its wisdom. Through those battles, humankind has not only achieved victory but also acquired knowledge used in the battles. Knowledge acquired in each battle has been accumulated as shown in Figure5. The

accumulated knowledge was classified into groups according to features of usefulness. Knowledge which belongs to a group achieved coherence and then starts to promote abstraction. At some level of abstraction, it acquires characteristic methods of logic and calculation. Consequently, the knowledge gains neutrality by being released from the basis of its origin in battle, and the scope of possible use expands beyond the battle with the enemy. Once these characteristic methods are completed, not only does the scope of use expand, but new knowledge can also be produced by processing only internal knowledge, without help of other knowledge. A group of knowledge which past this point can be called an independent academic discipline, and while physics and chemistry are representatives, economics is likely independent as well and many disciplines in engineering can be said to be independent under certain conditions, too. This can be understood from examples described below, of the construction of techniques through battles against evils and then the creation of academic disciplines through abstractions.

To defy storms, techniques for predicting storms and anti-storm technology were invented first, and then their universalization established meteorology and architecture. Likewise, many disciplines were born from battling evils: earthquake-resistant houses were built and later structural mechanics as its abstract science was established; sterilization fighting pathogens grew to microbiology; judgment systems to avoid evil desires grew to jurisprudence; debate resisting autocracy was the origin of logics; manufacturing technology to eliminate poverty created engineering disciplines. Also beyond evils, human's curiosity regarding the mysteries of society and nature that worried people led to the establishment of experimental analysis methods and thus the creation of a system of science. This scientific method was effectively utilised as the basis of many other disciplines.

The many disciplines that gained independence in this way originally aimed to understand their targets, but it is easily seen from their origins that those disciplines are useful for people's actions. After establishing

disciplines, researchers expanded knowledge in their particular disciplines as discussed earlier and published it in the form of scientific papers. Actors in society receive the scientific papers and used the knowledge in the papers for their own practices and thus influenced society and nature. Between scientific researchers and the actors as users of knowledge existed a thick dividing wall as shown in Figure 6, and there was no dialogue to influence each other. Knowledge transfer was a one-way street. Removal of this wall is exactly a challenging target to be accomplished now for the establishment of sustainable society based on science.



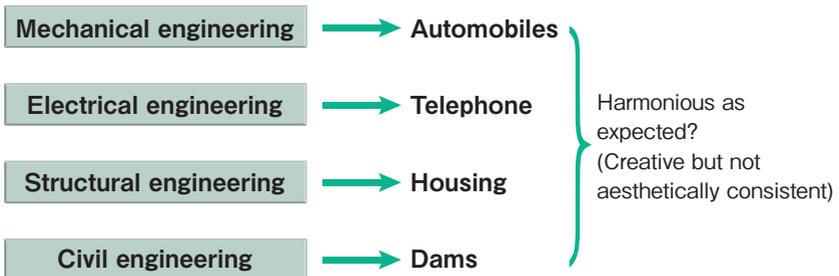
Scientific knowledge is used by people on the other side of the wall

Figure 6 The one-way street of scientific information

The problem is that even though the knowledge accumulated in many disciplines became plentiful, there was little knowledge about the connection between disciplines. This means the work of summarizing the knowledge of different disciplines into a single discipline is scientifically difficult and it was revealed by our research on mathematical integration of disciplines that it necessitates the participation of researchers from diversified fields including philosophy. The lack of progress due to the factual crawling pace of this operation is a difficult problem in modern science. As a result, social problems arising from the unexpected interaction between artefacts

born from specific disciplines have become more frequent. This can be understood from the simple examples shown in Figure 7.

Evils different from the ones which were overcome in the past are now emerging to challenge us, humankind, and they present us new problems far more serious than the ones in Figure 7. They form an almost endless list, with examples including population explosion and starvation, the expanding gap between rich and poor, poverty in megacities, degradation of the global environment, global warming, regional disasters, extreme growth of failures in artificial systems, new kinds of diseases (HIV, avian influenza, BSE), ethnic disputes, terrorism, isolation in cities and cybercrime, etc. These are not things attacking humankind from the outside like past evils, but rather invisible things concealed among our actions, and a simple fight like the resistance to the past evils are not possible. Under these conditions, humankind is confronted with new problems that request us to make a deeper consideration about ourselves and more real and practical self-analysis than before.



- Use of mobile phones not allowed while driving an automobile
- House architecture does not harmonize with car garages
- Disharmony like houses submerged by dam construction is born.

The disharmony that a design optimized by a single engineering discipline is not necessarily optimal in actual society reflects the structure of our knowledge.

Figure 7 Environmental deterioration by artefacts disharmony

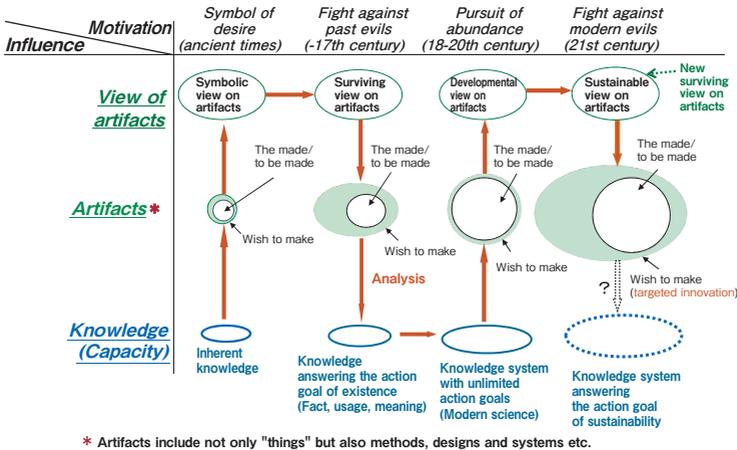


Figure 8 The atavism in view of artifacts

This is closely related to the change in view on artefacts which is presently arising. Through the long history of human beings, the view on artefacts has changed several times corresponding to the changes of environment as shown in Figure8 [9]. At present, the start of 21th century, we meet a big change in the view, from development by artefacts to sustainability by artefacts. We know that people always wish the emergence of new artefacts by scientific research. They are not only physical objects but also programs, software, customs, systems, laws, treaties and the like. Because of the change in the view, they are all imposed stricter conditions on their acceptance by society than in the 20th century.

As discussed above, the historical development and present status of scientific knowledge and the condition of acceptance by society cannot be ignored when we choose subjects of research in future. In order to set a guideline for selecting the research subjects considering the status and conditions, the process where scientific disciplines came into existence will be examined in a little more detail.

First, let us consider the traditional form of knowledge prior to the formation of disciplines in modern knowledge by scientific methods.

The knowledge in traditional form is presently observed everywhere in the world but it differs from scientific knowledge which is assumed universality. It represents local knowledge rooted in local environment, traditions and culture, and therefore is called "indigenous knowledge". This knowledge is diverse owing to its correspondence to the diversity of environment and culture on earth, but is common in that it is firmly based on traditions and everyday lives of people in particular local regions. This can be shown in an example as follows.

When considering the case of obtaining medicine for stomach ache from plants, locally growing plants are used for their healing. In this case, the evil is a disease. Here the knowledge, as shown in Figure 9, is first the knowledge of where to plant the seeds for good growth, when the plant sprouts and when it bears fruit. This is called "factual knowledge". Next, is the knowledge of when to harvest, how to extract the active ingredient, how to preserve it, how to prepare it for creating the medicine and how to take it. This is called "knowledge of usage". Finally, there is the knowledge of the resulting effect, which corresponds to the motivation and action of the user. The functional effect as a result of action is meaning, therefore this knowledge is called "knowledge of meaning". The chain of knowledge has three parts of fact, usage and meaning and maintains usefulness as a set.

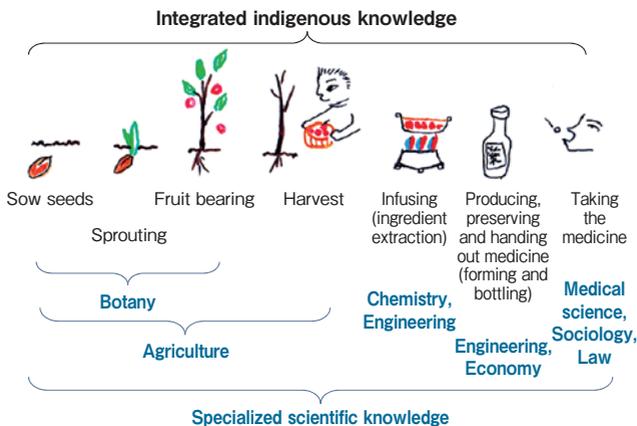


Figure 9 Traditional (indigenous) knowledge  
Example: How to overcome disease and survive

On the other hand, in scientific knowledge gained by scientific methods (as shown in Figure9), factual knowledge is systemized into botany, knowledge of usage is categorized as agriculture (also including factual knowledge), chemistry is derived from extraction and preservation, mechanical engineering from preservation and transportation. The method of taking the medicine, the effect or its meaning is systemized as medical science.

In scientific knowledge, indigenous knowledge is thus divided in this way and the practical meaning of the knowledge is lost from each division. Instead, botany creates a systematic and universal knowledge of all plants on earth, and agriculture also treats all useful plants in general. Extraction is not only universalized as scientific knowledge but also consolidated into systematic knowledge together with other methods for producing active substances, thus forming one discipline. The discipline consolidated in this case forms one branch of synthetic chemistry. In this way, the diverse local characters are abstracted and common global systematic knowledge is formed. In the process of refining this knowledge, disciplines are subdivided further into new disciplines. This scientific method, collection according to use, abstraction and systematisation, is a far more efficient method for acquisition, use, dissemination in society and inheritance through generations of knowledge than indigenous method. As a result, humankind has successfully gained a plenty of universal and systematic knowledge of nature and society.

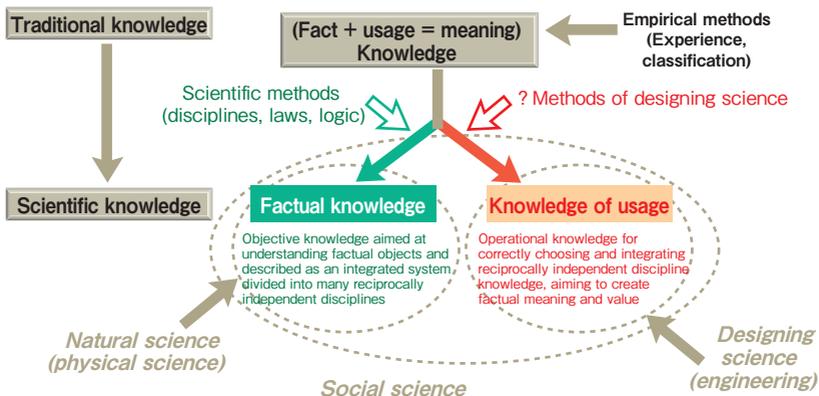


Figure 10 Natural science and social science

The process of forming scientific knowledge is simply illustrated in Figure 10. The formula "fact + usage = meaning" which characterises the indigenous knowledge resolves into a systematic scientific knowledge which is comprised of factual and usage knowledge.

Next, the diversification of disciplines will be discussed. It is known difficult to give a rigorous definition to scientific discipline, but here we give a simple definition for practical purposes.

**Definition of "discipline"** The establishment of a scientific discipline is triggered by a collection. A collection is the gathering of objects that have been intuitively judged as being related to a specific interest from special aspects such as property, behaviour and functionality. Through observation of elements in the collection, common parameters expressing this interest are selected. Then, rules deciding the relationship between these parameters are proposed as hypotheses. Hypotheses give birth to a theory, but truth of the theory must be verified by thoroughly inspection of the consistency between the theoretical predictions and the reality within the collection. If the truthfulness of the theory is verified, it is called a scientific discipline. This is shown in Figure 11. The level of ability to generate new knowledge by only operating the theory within the discipline is an indicator of the completeness of the discipline.

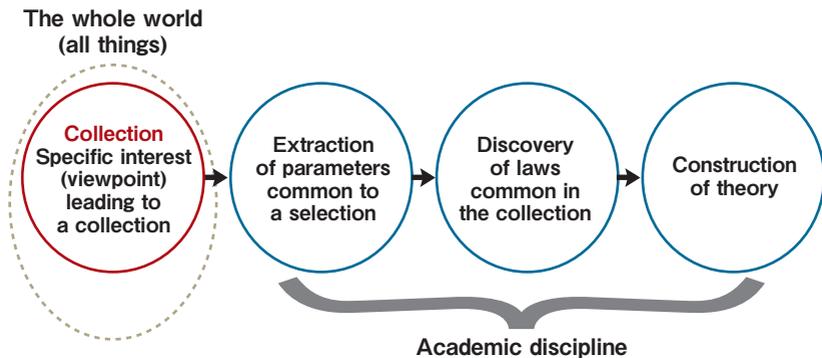


Figure 11 Constructing an academic discipline

In the example of Newton's dynamics, the movement of objects existing in the world was the interest, and therefore a collection was made whose elements were all objects in the universe which may move. An object was represented by a material particle which corresponds to the centre of gravity of the object. Mass, acceleration and force are selected as parameters expressing the status of objects. A variety of other parameters were discarded and the world is shown as a system of material particles. Then, the famous Newton's laws were introduced which perfectly describe the movement of any object in the space. Therefore, the Newton's dynamics is exactly the universal theory of movement of objects.

Besides the movement of an object which was interested in by Newton, scientists were interested in various phenomena and existent. They are really diversified: structure of matters in elementary physics, essence of life in biology, useful properties of substance like mechanical or electrical in engineering, or value of foods in nutrition science and so on, and specific interests are assigned to artefacts like compound materials or machines. Any interest is allowed to take for scientists and hence they are possibly countless. But it is common that interests which look new end up in the same discipline. Only an "independent interest" will be lead to a new discipline. In other words, unprecedented viewpoint or interest which drives the collecting actions is requested to give birth to a completely new discipline. Such viewpoints are limited to those that cannot be explained with existing scientific disciplines. If it cannot be explained, we identify that the interest is unprecedented. Before trial of explanation, we cannot say if the interest is new or not. Therefore, we must call this specific interest an "intuition". Therefore, a collection is made intuitively.

It is obvious from this definition that scientific disciplines are not formed systematically. When scientists are interested in some phenomena or existent and take up them as the subject of research, there is a possibility for them to be grown into a scientific discipline.

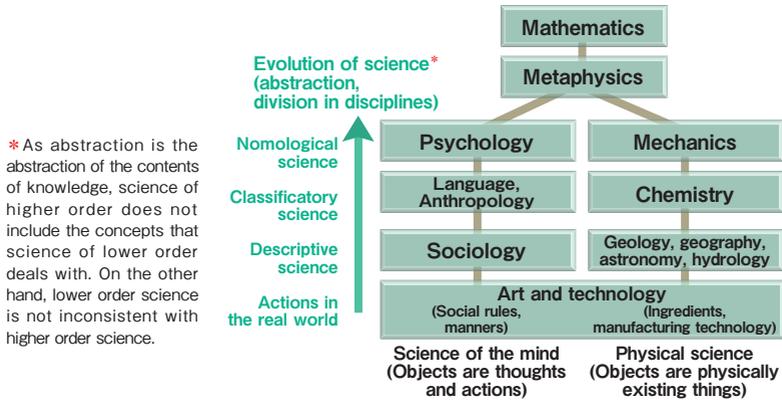


Figure 12 Categorization of science according to Charles Sanders Peirce (1839-1914)

Peirce refers to this growth, proposing a categorization of scientific disciplines by "abstraction level", starting with the most concrete everyday knowledge and ranging from descriptive science, classificatory science and nomological science, and finally to metaphysics and mathematics [10]. This is shown in Figure 12. According to Peirce, scientists have created universal knowledge being driven all the time by the motivation to abstract their objects. Apart from metaphysics and mathematics, the direction of the abstraction level in the figure from low to high is the historic process of progress in science. In this sense, the first everyday knowledge could be thought to correspond to the indigenous knowledge mentioned above. Thus, the rules of the relationship mentioned in the definition of discipline accord with the progress of abstraction: descriptive rules, categorization rules and principles. The systems in the completed discipline are respectively systems of explanation, of categorization and theory.

By the way, the Peirce figure shows that there are two parallel systems of mind and substance and the both progresses their abstraction level. However, in present knowledge, the biological organism must be placed between mind and substance, as it does not belong to these two but it is the biggest interest among science community. The objects which

appear in biological science are obviously regulated by specific rules other than mind and substance. Substance does not possess life and the laws of physics regulate its existence. At present, the existence of biological organisms cannot be explained by using only the laws of physics but needs the life scientific information represented by genes. The phenomena of the mind like family, society and so on, are regulated by specific rules which cannot be understood by life science.

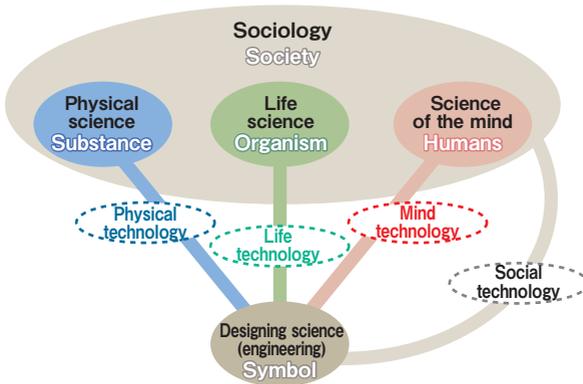


Figure 13 Science and technology

Therefore, the division of disciplines into substance, life and mind clearly exists in spite of the complex diversity of disciplines. By considering this division neglecting the aforementioned division of abstraction levels according to Peirce, we can draw a sketchy diagram for categorisation of scientific disciplines in Figure13, showing the relationship between the division into substance, life and mind, and the division into factual knowledge, knowledge of usage and knowledge of meaning. This figure shows that the group of disciplines organized respectively as materials science, life science and the science of mind has corresponding knowledge of usage in the form of the respective technologies of physics, life and mind. This diagram stands on a premise that the knowledge of usage is independent of kind of objects, or in other words, the general design method that is independent of objects must exist. It has been progressively

understood that there can be theories which deal with design process by symbol processing. This shows the possibility of producing practical design technology by applying a common theory of symbol processing in design to overcome the tremendous complexity of design objects which sometime disturbs the optimality of design. However, this has not reached the step of practical applicability and is a subject of basic research called general design theory. The figure further shows that sociology is dealing with the knowledge of meaning and social technology must be based on the design theory.

In this way, the structure of diversity of scientific disciplines is understood. The diversity has three axes:

- (1) Diversity by division in factual knowledge, knowledge of usage, and knowledge of meaning (3 kinds)
- (2) Diversity by level of abstraction (4 kinds according to Peirce)
- (3) Infinite diversity produced by the specificity of interests (3 kinds roughly divided into lifeless substance, biological organism and mind).

Modern scientific knowledge is of course not perfected but is still in the midst of development, and it means, needless to say, that the basic research is of the central necessity for knowledge acquisition. Table 3 shows the specific interests or objects that seemed to be the opportunities for establishing disciplines and the present scientific disciplines which might have grown from those interests.

In this table, disciplines are categorized in order of completeness level, namely as disciplines, matured preliminary disciplines, established preliminary disciplines and incomplete preliminary disciplines.

The definition of disciplines and preliminary disciplines here is:

- (1) Disciplines: Academic disciplines (in contrast to preliminary disciplines as described below) are called just disciplines if they are not created by human intent and were established with the objects of study being natural things including substances and organisms, humans themselves

and naturally occurring things related to humans like language or society.

- (2) Preliminary disciplines: Disciplines targeting artifacts. As artifacts change through time and do not persist eternally, disciplines taking such things as an opportunity for study are called preliminary disciplines.

Disciplines as well as preliminary disciplines show different levels of systemization or, according to Peirce, abstraction level, but as innovation also creates artifacts, the level of preliminary disciplines holds an important meaning. Therefore, the categorization of maturity, establishment and incompleteness is shown only for preliminary disciplines. If we follow Peirce, incomplete disciplines are everyday knowledge (indigenous knowledge), established preliminary disciplines correspond with descriptive science, and matured preliminary disciplines with categorizing science (and to some part science of principles) and disciplines with science of principles. If categorized this way, disciplines turn out to be mostly factual knowledge. As discussed below, this is the reason a special system of cooperation between researchers is necessary to advance innovation.

| Object (example) |  | Discipline (example)   |   |
|------------------|--|------------------------|---|
| Nature           | (Substance) Atoms, molecules, crystal, rock, heat, fluid<br>(Organism) Plants, animals, cells, organs, human body, physiology<br>(Mind) Intellect, logic, language, primitive service<br>(Society) Society, people, settlement, family, marriage, law            | Discipline             | Physics, chemistry, mechanics, thermodynamics, astronomy, earth science<br>Botany, zoology, anatomy, physiology, molecular biology<br>Philosophy, psychology, logic, linguistics, literature, aesthetics, semiotics<br>Historical science, sociology, cultural anthropology, philosophy of law, ethnology                     |
| Artifacts        | Matured Artifacts  | Preliminary Discipline | Matured * Discipline  |
|                  | Established Artifacts  |                        | Established * Discipline  |
|                  | Artifacts not belonging to existing disciplines  |                        | Existing incomplete Discipline  |
|                  | (Substance) Machines, ingredients, elements, structure<br>(Organism) Health and disease, agricultural produce, prepared food, live stock, poison<br>(Mind) Information, education, literature and arts, service<br>(Society) State, economy, finance, trade, law |                        | Mechanical engineering, materials science, electrical engineering, structural mechanics, architecture<br>Medical science, pharmacy, pathology, agriculture, nutrition science<br>Information engineering, pedagogy, theater studies, literary criticism, service engineering  |
|                  | (Substance) Industrial products (cars, air conditioners, communication devices)<br>(Organism) Genetically modified organisms<br>(Mind) Modern theater, literature and arts, journalism<br>(Society) Business, electronic government, environment                 |                        | Automobile engineering, thermal engine science, communication engineering, production science, transportation science, regenerative medicine, nuclear medicine, organic risk<br>Avant-garde esthetics, financial engineering, media science, economics, environmental science, science of disaster prevention, safety science |
|                  | (Substance)<br>(Organism)<br>(Mind)<br>(Society)   |                        | Objects that cannot be treated by existing preliminary disciplines<br>Collection of knowledge necessary to when designing products, systems, institutions and so on that consider the environment   |

\*To be precise, these are respectively "matured preliminary disciplines", "established preliminary disciplines" and "existing incomplete preliminary disciplines"

Table 3 Academic Discipline

## 2.2 Tasks in the relationship of knowledge disciplines

When we apply the modern scientific knowledge to the information cycle loop, current situation of modern scientific knowledge is found to assume the following insufficiencies: the weakness of observing scientists' interest in the changes which are presently proceeding in nature and society and holistic observation regarding these changes, the immaturity of methodology to be used by the designing scientists, and lack of cooperation among observing scientists, designing scientists and actors.

The last chapter outlined the situation of scientific knowledge from the viewpoint of disciplines. In this chapter the nature of the relationship between disciplines will be discussed. By investigating the loop which scientists participate in as in Figure 2 of Chapter 1, we will examine the nature of disciplines and of the relationship between them that is necessary to realise the sustainable evolution. The examination tries to identify the research subjects needed for innovation.

The abundant knowledge that is highly organized today are listed in Table 3: the "nature" in the left column designates the natural existents and the knowledge about their properties. By natural existent we mean objects that exist naturally without specific human will, and the corresponding disciplines called science (natural science, sociology, humanities). Here we categorize the intuitive human actions such as language and primitive service into natural existent. This abundant knowledge was achieved through collection and systematization by observing scientists and explains well the properties of existing things. Metallurgy, for example, explains in detail the general properties of metallic elements, and it has become possible to widely predict the behaviour of all sorts of metals depending on the given circumstances. In mathematical economics, economic phenomena are analysed using mathematics to understand the economy as a whole and predict the future under given conditions.

As the main purpose of modern science is to uncover the truth, that is to find out the principles which exist and operate behind the appearance

such as existents or phenomena, it is normal that there is not much focus on the aspect of "What is the status of this object in the present world?" Phenomena themselves under such specific conditions possibly hide their principle or the truth behind, and it can be said that gaining this knowledge in this aspect is not a part of the mainstream of scientific research. These circumstances are illustrated in Figure 14, which shows the specific procedure of the observing scientists' research. In scientific research, the object is selected by specific interest, and the selected object is the collection. However, to understand the fundamental properties of this collection, the basic thing to do is to exclude the special characteristics of the situation for each element of the collection, or to understand the properties not affected by the present conditions. Properties appearing under present conditions are therefore not the truth but simple phenomena. As a result, element of selected collection is placed in an experimental condition and given a stimulus explicitly and deliberately planned which is different from stimuli where the element was exposed in nature. Then the truth is extracted from the relationship between the stimulus and phenomenon under such conditions.

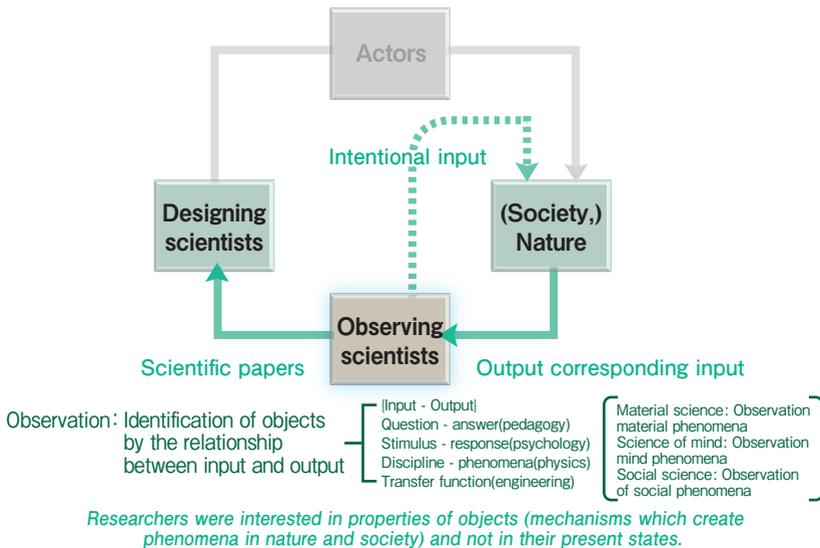


Figure 14 Modern science

In the end, the properties are understood as the relationships of stimulus and reaction, occasion and behaviour, and input and output, but stimulus, occasion and input have to be intensionally planned in laboratory, and not the real condition. As the results in Figure 14 show, the output produced by input is observed, and the relationship between both is used to "identify" the truth behind the appearance of nature and society. Therefore they are placed in the middle of the small loop that is closed for the sake of research. Therefore the results obtained by the observing scientists are not dynamic situation of nature and society which enable us to detect the changes of the world on the cycle, but only the static truth, and so it must be said that such observing scientist does not fulfil its role in the loop as one of the participating member in it.

Even if the fundamental properties are identified, it is impossible to predict the path that nature and society follow in the future as evolution. The insufficiency of scientific knowledge for predicting this path is easily understood by surveying the outline of modern scientific disciplines given below.

**Example 1** When scientists became interested in the invariability of existing things (Democritus' atom), they examined the microscopic properties of matter and created scientific disciplines which are useful to understand this invariability. There are scientific disciplines obtained in this way, which are listed as follows:

- (1) Theories based on the principles of existence: solid state physics, chemistry, elementary particle physics, molecular biology, etc.
- (2) Theories of the principles of microscopic change: diffusion theory, theory of chemical reactions, embryology, etc.

Their study has created independent disciplines of their own, and the level of completeness of each scientific discipline is high.

**Example 2** When scientists became interested in the change of existing things (Heraclitus' "panta rhei", "everything flows"), they examined the whole of matter as an object and created effective scientific disciplines to

understand this change. The disciplines are as follows:

- (1) Theories based on the principles of macroscopic change: geology, archaeology, paleontology, etc.
- (2) Theories of the principles of the causes of change: theories of evolution, geological stratum formation, climate change, etc.

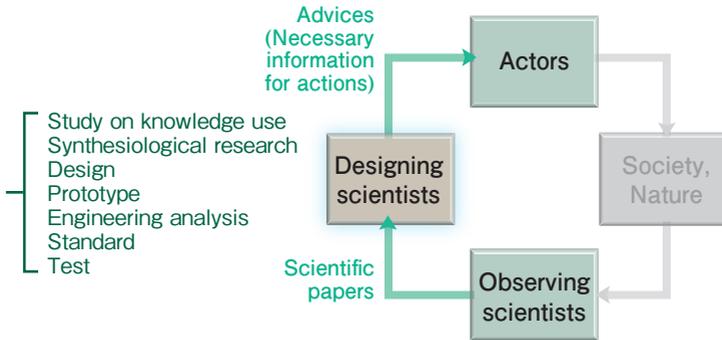
Their study could not create independent disciplines and the level of completeness as disciplines is lower than the examples 1.

Thus, we must recognise that the scientific knowledge to understand the reasons of the present state of the world is insufficient. Moreover, in this situation, the holistic observation which is the necessary condition that drives the proper cycle for the sustainability mentioned in Chapter1 is not only unsatisfied, it has to be also recognized that the observation of circumstances, a prerequisite for the holistic observation, is insufficient. This means that basic information necessary for sustainable innovation is not presented well to the designers. It should be stressed here, that this is a serious problem one must be aware of when proposing research subjects to researchers enabling innovations. It will be a main topic in drawing up the "structured panoramic view" in Chapter5.

Then, what about the designing scientists? Most of them are in disciplines called engineering (including the research of social technology), and because they are conducting research with the aim of creating new value using scientific knowledge, they are leading actors of innovation. Alongside creating basic knowledge themselves, and as it may well be said that they are using the abundant knowledge created by the observing scientists, it may also be said that cooperation with the observing scientists, as shown in Figure15, is quite common. However, design scientists are lack of a methodical maturity. In most cases, as a method of design they focus entirely on the empirical accumulation, one by one, of research subjects concerned with design for innovation. They fail in pursuing a general method, so diffusion of designing methods is slow and inheritance efficiency is low. Therefore, the improvement of social ability for design is extremely slow. This is one of the main causes obstructing innovation which is

urgently requested for sustainability.

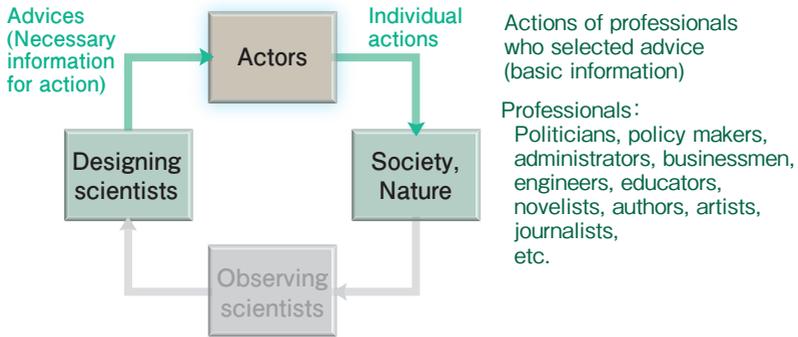
The insufficient systematisation of design process by designers has been long time pointed out by researchers and designers. In order to efficiently drive the information circulation on the loop, the systematisation of the design process is inevitable. It was already shown that there is a specific phase of research which is difficult to conduct systematically. There are three phases in research for innovation [6], dream, nightmare and reality phase. First is the basic research where researchers find out problems to be solved and analyse them. This phase is called dream phase of research, which roughly corresponds to the observing research in the present context, where researchers enjoy a plenty of established methods of research. The second is the tough phase, called nightmare phase, where researchers suffer from the shortage of systematic methods. This phase includes design of products, planning of actions, policy formulation, bill drafting, and composition of art works which may be called design as a general term. It is known that this phase is hard for researchers because its success is highly depend on incidental chance and trials often end in failure without reward. Moreover, researchers have less chances to get research fund than the first phase, and hence less opportunity to be promoted. It is worth noting here, however, that this second phase "nightmare" is the most important one to go through toward the reality of innovation which is the last phase interested in by industries. Without going through this phase, any innovation based on basic research cannot be realised. Difficulties found in this phase are almost the same as those met by design scientists of the present definition. Therefore, it is crucial to overcome these difficulties in order to improve the efficiency of information cycle on the loop of sustainable evolution. Works to solve this have begun in some areas [11], but its wider expansion is desired.



*Researchers were satisfied by just accumulating knowledge of individual synthesis and not successful to establish general theory of synthesis.*

Figure 15 Modern engineering

Actors as the actual innovators in society are the next subject. There are various actors in society. If we think of professions in society, we may pick up educators, engineers, managers, politicians, policy makers, administrators, lawyers, judges, police officers authors, artists, journalists, and so on. Their actions are more or less based on scientific knowledge and resulting innovations give influence on society. We may thus say that their actions are linked directly or indirectly to innovation. It is not easy to generally measure how these actors contribute to the green innovation and life innovation which are our present concerns, but it is an important point for us research strategy planners to be always aware of. These actors basically act after receiving advices from the designing scientists (in reality by gaining scientific or technological information in some form), as shown in Figure16. Yet, this receipt is one of the arguable problems being connected to the decision-making cases in society and regrettably frequently produces conflicts, even if actions are apparently based on scientific advices. From the perspective of scientists and research, here lie tasks of having to advance the methods of proposing advices to society [12]. One of the most serious issues is the decision methods of science and technology policy by government. This will be discussed elsewhere.



*Actions by actors in society are unpredictable: neglecting or rejecting advices, and sometimes their selections of advices are arbitrary.*

Figure 16 Actor's Actions based on Scientific Advices

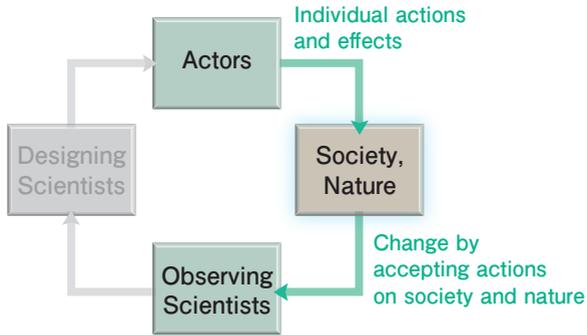
Now, it is the time to discuss the last block of the loop: nature and society as target of scientist's endeavour, which we expect to grow into a state in future that would satisfy their prosperity and sustainability harmonically. Various actors act in society and bring some effects, resulting at least partial changes which might be local in nature and society. Some of those local changes, when accepted by society, is possibly disseminated widely into nature and society. This dissemination is driven by "social technology" and generates an observable change in nature and society. We are targeting those changes toward "prosperous sustainability". However, this target is just too big from the perspective of research development subjects. It is pointed out here only that for nature and society to move toward a desirable direction, social technology supported by scientific knowledge is necessary (see Figure 17). Here, we simply define social technology as a technology which is based on social science like (natural) technology based on natural science. Social technology, which is crucially requisite for dissemination is still at the level of infant discipline. It will be discussed elsewhere. Finally, these changes are detected through the holistic observation by observing scientists, and thus the loop is completed.

Now, let us sort out what problems exist in the information cycling over the loop as a whole by considering the reality of modern science. All of the elements forming the loop have factors obstructing the cycle, as summarized in Figure 18.

These include:

1. Insufficient actual observation of changes in nature and society by observing scientists
2. Lack of holistic observation of changes by observing scientists
3. Arbitrariness in the selection of research subjects by observing scientists
4. Insufficient cooperation between observing and designing scientists
5. Methodical immaturity of designing scientists
6. Insufficient exchange between designing scientists and actors
7. Ambiguity in the selection criteria of actors' action
8. Excessive reliance on apparent requests in society in the process of subject selection by the actors
9. Ignorance of the relatedness of actions of actors in society
10. Insufficient development of social technology

Considering that the evolution of the loop lies in the incremental actions of the actors, and that those diversified incremental actions in society are difficult to be subjects of scientific research at the moment, Points 7 to 10 will not be discussed in this text. Points 1 to 3 regarding the observing scientists are a major subject for research strategy. They are actually related to the discovery of invisible social wishes to be discussed in Chapter 3 and will be explained in detail in Chapter 4. Points 4 to 6 on the designing scientists have to do with the design theory, design methodology and integration or bundling of scientific disciplines, together with the cooperation between researchers, the organization of researchers and designers. The research strategy related to these subjects will be dealt with under the title of the "structured panoramic view" discussed in Chapter 5.



*This transition is one research object of social science, and **social technology** is designing this transition.*

Figure 17 Social Technology

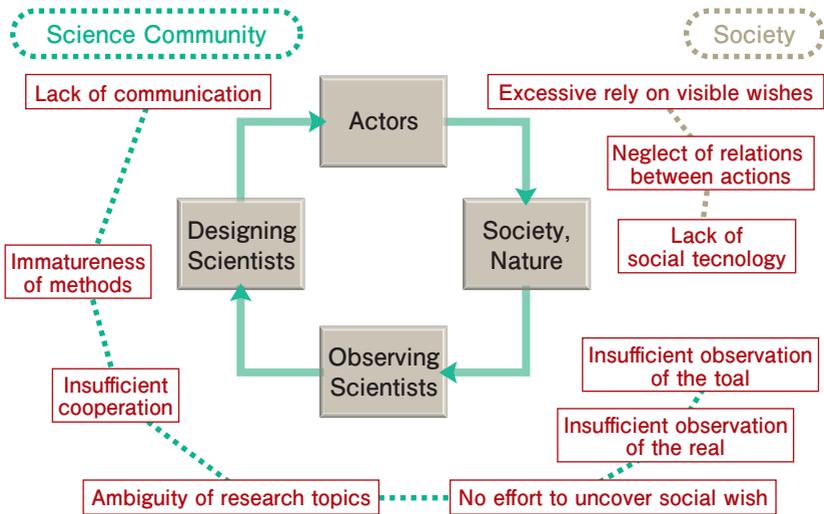


Figure 18 Reluctances to Circulate

## Social Wishes

### — Analysis of Social Wishes

The expanse of social wishes differs, they collide with each other and the viewpoint on distance from technology varies, but it is possible to categorize them into the following three levels: (1) prerequisites and given conditions, (2) visible social wishes and (3) invisible social wishes. Among these, the discovery of the third level of "invisible social wishes" is the most important to design research and development strategies.

In order to exclude arbitrariness and self-righteousness from superficial desires in society and to accommodate social wishes to the fundamental necessity of mankind, new scientific research is necessary on the "discovery of social wishes", by observing the total change brought into society and nature by the actions of actors (holistic observation). When social wishes are discovered, which must be hypothetical at this stage, scientists should not force society to implement them but to entrust society to select wishes for implementation by its own judgement while showing the possibility of implementation through science and technology. This is requisite for scientists to avoid falling into the trap of self-righteous social wishes.

There are already many suggestions for social wishes and proposals of technological means that may solve them eventually. However, there are only subjective explanations as bases for these suggestions and it must be said that an objective or scientific basis for each suggestion is definitely lacking. As a result, technological means proposed is inevitably intuitive or arbitrary. One might think this unavoidable, as a wish is not something expressed logically in the first place. However, scientific analysis of social wishes is of requisite because they are the most important starting point for "basic research for society".

The long history of science, research of which has been conducted within a community where scientists maintained rules of autonomy and of intellectual-curiosity drive in research, guarantees neutrality of scientific knowledge which is not affected by special interest in society. As a result, scientific knowledge becomes objective knowledge universally valuable to anyone. Human beings had learned that the intellectual curiosity driven research only can provide humans with universal knowledge. However, mankind is now confronted with many difficult problems such

as environmental changes represented by global warming, scarcity of resources accelerated by rapid growth of population, financial crisis, increase of local disasters, etc., and they are expected to be solved by applying scientific knowledge. Therefore, it has become urgently needed for the survival of mankind to create relevant knowledge to overcome these difficulties. It must be recognized that humans are now in a situation where actions are needed urgently using relevant scientific knowledge in the available time. Method of acquiring knowledge in historic way mentioned above is needless to say still right, but here is a serious question if enough knowledge is available in time by the method. A new concept "basic research for society" was recently proposed by Prof J. Lubchenco to compromise contradiction between the autonomous research which is never influenced by the societal desire and the research creating basic knowledge requested by society in the confrontation with modern problems. From the standpoint of "basic research for society" and when thinking about mankind desiring knowledge necessary for survival, it must be immediately realized that we are in a condition where we have nothing but an abstract and ambiguous understanding about what subjects to solve as a prerequisite for survival. At a stage of research where research subjects are not explicitly designated, it is highly probable that the necessary knowledge is not obtained simply by combination of existing knowledge, humbly recognising that present science has not uncovered yet everything in the universe. Therefore, a major subject of the present age, referred to as the age of sustainability, is to conduct new basic research for society to find new basic knowledge relevant for sustainability. The discipline "discovery of social wishes" seems one of these basic researches which had not found in the traditional category of basic research.

Social wishes are subjects that must be responded urgently, but that needs to be "discovered" first, are not only things recognized by society but also includes wishes which are no more than indefinite silhouettes that people hold in their hearts, wishes floating in society and also wishes not yet perceived by humanity. We define these kinds of social wishes are the starting point of process designing policy and subject proposals

in the research and development strategy. In the age of sustainability, the importance of social wishes which are starting points of research and policy development is increasing.

If we again take a general view of the examples of social wish as described above, we find a great variety of social wishes. First, there is "diversity" of the wish, from broad wishes concerning all of mankind globally such as in the case of global warming prevention to narrow wishes concerning individual problems such as health maintenance. Then, there is "conflict" of wishes such as access to biological resources that benefit all in the long term but produce local conflicts of interest in the short term. Finally, as can be seen in many examples, "distance" from wish to technological solution, which metaphorically designates the necessary effort or investment for the realisation of wish, varies.

These problems concerned with diversity, conflict and distance will be discussed later. Here "levels" will be summarised as essential aspects of social wish. Specifying the classification of levels will become important for the scenario-building hereafter.

The first level of social wish involves given conditions under particular circumstance, which might depart a little from the word "wish" but are of the utmost importance and inevitable. These conditions are extremely difficult to change and impossible to ignore regardless of the scenario created. For example, in the case of our country Japan, there are certain given conditions of geography and climate. Another is population decline. Besides these, there are international relations and the like. What is taken as a given condition may depend in part on judgment, but it is necessary to clearly point out before the start of design of strategy. Social wishes in this level are thus the basic conditions for design.

The second level corresponds to social wishes already expressed in society. At present there are already various wishes widely known in society such as environmental sustainability, improvement of people's health and

wellbeing, and preservation of Japan's original culture to contributions toward a sustainable world etc which can be quoted from Basic Plans of Scientific and Technology, published by the Cabinet Office. As already mentioned, wishes entering this category are aimed to cover those admired by everyone, but the coverage cannot be perfect because of difference reflecting conditions of states or regions and individual philosophies which are not uniform. Detailing these in this category will be done in the investigation undertaken in the future.

On the other hand, there should be social wishes not expressed explicitly at the moment in society but could emerge and perceived in society sometime in future. Social wishes of this category are called potential wishes. The research aimed at discovering these invisible social wishes is expected to become the most important subject in the design of research strategy for innovation in the future. It is important to note that the discovery of this potential/invisible wishes could be conducted by the observing scientists.

The categories of social wishes are summarised as follows:

1. Prerequisites and given conditions (to be socially agreed as conditions imposed to targeted subjects but not changeable by policy)
2. Visible social wishes (to be selected by survey through scientific papers, literatures, and other documents.)
3. Potential/invisible social wishes (to be discovered: scientific research including theoretical and experimental)

The 3rd category may be conducted by autonomous scientists independent of special interests of society. They are basic researchers including humanities, psychology, medicine, (humans), social sciences (society), and natural sciences (nature).

Social wishes, in 2nd and 3rd categories are mostly talked about as conditions desirable for humans and are in general not concrete. Generally they are described as "functional desire". Functionality is a familiar concept in everyday use, but its definition and classification are not clearly understood [13]. Consequently, describing categories of social wishes is

not possible in a strict sense or scientifically. For the sake of convenience therefore, we classify the wishes by the scientific disciplines considering social wishes to be implemented by using them in the future. This makes a classification below possible.

- Life science (health): medical care, food, water, healthy environment, sustainable biodiversity, etc.
- Substance and materials: resource saving, energy saving, energy recycling, sophisticated machines, etc.
- Information: social information system, information availability, dependability, green IT, etc.
- Environment: Climate change control, change adaptation, disaster reduction, land conservation, etc.

However, this categorization is made intuitively for the sake of convenience. It must be recognized that these allotment of functions to scientific disciplines should not impose any limitation to research activity which will be conducted free of them in the progress of research stages.

It is useful to draw a diagram of panoramic view of social wishes for understanding the social condition as a whole and for necessary technology for each wish in general. However, the panoramic view available at this stage is not more than conceptual and does not lead directly to research development strategy decisions.

As mentioned before, social wishes are known to have many and complex contents. It is easily understood that social wishes sometime correspond to people's sense of value individually and are connected to various organizations like states on the others. Wishes are cast toward either nature or artefacts. Such complicated object cannot be depicted easily, and may be one which should not be drawn as a unique object. According to Popper [14], it is forbidden to draw whole image as a target of action when the subjects include complex and various elements, such as social systems. He insisted piecemeal approach is only possible to get the final solution. This is closely related to the loop for sustainability discussed in Chapter

1 and to the "holistic observation" by observing scientists. Following the categories in Chapter 1 Table 1, there is a category of "incremental actions and holistic observation", where actors are required to take actions of piecemeal or incremental steps toward social wishes derived by holistic observation of observing scientists. In this case, each piecemeal action does not cause piecemeal results but cause complicated changes in society and nature, which are to be observed again by holistic way.

This however does not mean that we are not allowed to draw general or society-wide social wishes even though social wishes belong to individuals. It should be noted here that it is strictly forbidden that anyone draws a holistic image by arbitrary theory, by selfish ideology or self-righteous power without people's inspection. When social wishes are discovered scientifically and published under the condition of possibility of scientific implementation, they can be subjected to the people's judgment. Because of the possibility of inspection preserved in this case, it does not violate the Popper's prohibition. .

In the following chapter, a method will be proposed where social wishes and scientific knowledge are coupled considering the possibilities for real implementation in society. In this method, an observing scientist who discovers and proposes a social wish and a designing scientist who suggests a feasible scientific-technological means to satisfy the wish meet together on an equal footing. This is the "encounter" of both scientists, observing and designing, and theoretically prevents self-righteous decisions by their scientific integrity. The topic of the next chapter is this encounter.

## 4.1 Problem statement

No method to describe social wishes systematically exists. Using an approach of analysis or elaboration of social wishes which are expressed in an abstract or conceptual way by their function, we discuss here the transition process where social wishes are transformed into research programmes in science and technology.

In this chapter, we discuss the elaborating process of social wishes which is a chain of incremental steps of their transformation toward the encounter. Here, we introduce a concept "basic research for society" which is different from the pure basic research widely accepted as research based on the spontaneous motivation or intellectual curiosity of researchers arising independently of social conditions including social wishes. Rather, the basic research for society here is that done by scientists who recognize the need for scientific knowledge, usage of which may benefit the betterment of people's life or protect the modern society from dangers it presently faces. Therefore, the researchers' curiosity should emerge through their learning social wishes, and their researches might aim at satisfying the social wishes they have identified. Thus the discovery of social wishes requests researchers to create new scientific knowledge not yet existing. The creation of basic knowledge which will be the bases of actions to meet social wishes may be called "basic research for social wish" which is a new kind of basic research. It is a research based on scientist's own motivation, who realizes the challenges in modern society.

Regarding such research, it is generally expected that a research subject contains certain social wishes although the researcher's motivation is given by themselves. Therefore, in the presentation of a research project, its planner is requested to explicate that the result will satisfy those social wishes. The explication must assure the satisfaction of these wishes by a scenario described relevantly to scientific knowledge available.

As understood from the last chapter, social wishes are often expressed

abstractly. They are sometimes expressed more explicitly with technical detail, where the wishes lose wider possibility to be satisfied by different technologies. However, when expressing a wish abstractly, it is difficult to definitely identify a method of satisfying the wish. In order to dissolve this contradiction, it is necessary to refine the social wishes. This refinement process is called the "expression problem for the refinement of social wishes". This problem seems to be analogous to the basic rule of design process that the quality of the design improves when designer is patient enough to think thoroughly the available technologies as many as possible before nominating a candidate of technology to be checked its feasibility. The social wish corresponds to a design specification in the design process.

It seems, for example, easy to incrementally raise the level of satisfaction of the wish by the improvement of existing technology, but it is difficult to make a great stride in the satisfaction without innovation which is to be realized by novel invention based on science and technology. Such a novel invention cannot be realized by incremental changes of technology but might presumably be created by unexpected technologies not existent so far. Such unexpected technologies do not emerge when thinking within particular domain of technology. On the contrary, it becomes highly probable to attain them when thinking patiently maintaining the thought process within the wish by analysing, fractionating and interpreting it. This process increases the accuracy of expression of social wishes. But as social wishes include various academic disciplines and values, there is no systematic method of their expression. Let us now address the question of whether a general method of refinement exists for the accurate expression of social wish which apparently looks abstract and vague. We shall try an example as follows.

Figure 19 shows subjects necessary for implementing sustainability in nature and society. This can be said to be a panoramic view of social wishes, and the horizontal axis shows the scope of wish implementation or reach of action, namely local, national and global. The vertical axis shows the scale of action by acting agents extending from molecules and atoms

to society and can be called "the atomistics of design" in the general design theory.

This figure is effective for gaining a panoramic view of what the world wishes with regard to sustainability, but individual wishes are only described in abstract manners and it seems difficult to find out and visualize the necessary scientific and technological knowledge which might solve them, as the distance between those subjects and possibly relevant technologies is too far to meet.

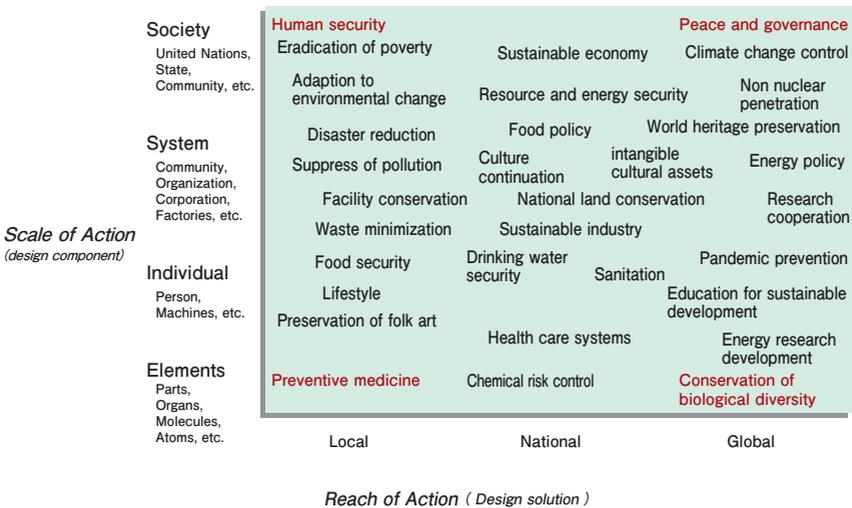


Figure 19 Actions necessary to realise social wishes (sustainable society)

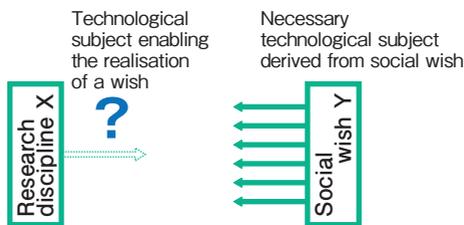


Figure 20 Refinement of expression toward the technology of a social wish

Figure 20 shows schematically the shortening of the distance by finding connection between social wish and relevant technology. The social wish is more and more detailed, then elements of the wish obtained by the detailing will finally have chances to meet respectively relevant technologies, the total of which may satisfy the original wish. At this place there is a connection, as shown in Figure 20. In the following sentence, this process will be shown as an example of sustainability.

First, the axis of Figure 19 will be detailed. Table 4 represents one example. The Reach of Action on the horizontal axis is the scope of the result of actions and categorized as "local", "national" and "global" in the figure. In regard to humans, categories are named as individual, family, society, region, state, area and world. The Scale of Action of the vertical axis then can be shown as atom, designated components (decided appropriately for each problem in question), individual (in the case of things an independent object), organization (system), region (infrastructure), and state and region. The world as a whole may never become one action component. If the main entities of decision-making are called actors, the next column in Table 4 shows the various actors. Then, the knowledge to be used is selected by considering the actors, which is written down as academic disciplines. The disciplines will be then designated more finely.

Let us take up biological diversity as an example. When thinking biodiversity only locally, the final goal of biodiversity on the earth will never be solved. Therefore the reach of action has to be the world. On the contrary, the diversity is determined by the preservation of every single species of animal and plant and the preservation is affected by events on the genetic level, so the molecular or atomic level is necessary in the scale of action. If the biological diversity is to be maintained under the agreement of all countries, the actors must be state governments. But real actors must involve relevant professional people of not only natural scientists, but scientist of various disciplines such as engineering, agriculture, economics, political science, law and sociology.

| Sustainability problem | Reach of action | Scale of action      | Actors                   | Method / Knowledge (discipline) | Method / Knowledge (arbitrary discipline) | Research          |
|------------------------|-----------------|----------------------|--------------------------|---------------------------------|---|-------------------|
| Peace                  | World           | Area                 | United Nations           | Humanities                      | Research areas                            | Research subjects |
| ⋮                      | Area            | State                | National governments     | Sociology                       |   |                   |
| Biodiversity           | State           | Region               | Municipality Corporation | Political science               |   |                   |
| ⋮                      | Region          | Organization         | NPO                      | Economics                       | CRDS Proposal                             | CRDS Proposal     |
| Health                 | Society         | Individual           | Managers                 | Education                       |   |                   |
| ⋮                      | Family          | Specific components* | Lawyers                  | Agricultural science            |   |                   |
| ⋮                      | Individual      | Atom                 | Farmers                  | Medicine                        |   |                   |
|                        |                 |                      | Authors                  | Engineering                     |   |                   |
|                        |                 |                      | Med. doctors             | Natural sciences                |   |                   |
|                        |                 |                      | Engineers                | Abstract sciences               |   |                   |
|                        |                 |                      | Scientists               |                                 |   |                   |

Diversity

Disciplines: Natural sciences, engineering, social sciences, science of the mind

Size: Nano Micro Meso Macro

Expanse: local to wide area (individual - society)

Actors: Individuals, organizations, governments, UN

}

\* Components decided especially artificially with the aim of specific change (Materials or organisms belong here; actually diverse)

What talent and knowledge is necessary for implementation? (Education, research)

Table 4 Axes of sustainability

By building logical connections between the reach of action, scale of action, actors, professional knowledge, observing scientists, designing scientists, advice and research subjects in this way, social wishes appear to be described in terms of scientific research, incrementally more accurate. However, even if this can be done conceptually, there is a major problem yet to be solved when thinking about the actual actions. In the case of biodiversity, the reach of actions is the whole world. The scientific knowledge about the life in the world can be described by distribution of species on the earth, where their genes are not elaborated. It should be noted here that the useful actions to maintain the biodiversity cannot be derived from this description, although we know definitely the status of diversity. The knowledge in such macroscopic description is unfortunately not adequate to suggest useful actions. It is necessary to go further, into more detailed knowledge of diversity in order to reach the stage of practical actions. From the macroscopic description of distribution of plants and animals by names of species in the earth, scientists must

go to the microscopic mechanism of their evolutions described in terms of genes, maybe considering the effect of climate and geology. Then, scientists will find useful methods to affect the diversity. They can be designation of protected areas, preservation of balance between species of plants and animals, control of chemical constituents of soils, etc. These are scientific actions which respond the necessity to preserve biodiversity which is one of the urgent social wishes. From this example, we know that the conceptual social wish, which is described in terms of functional requirement, will meet an actual method by which a practical action is practically derived, through such process of detailing from macroscopic wish to microscopic wish. Here, let us call this meeting as an "encounter" between a social wish and scientific actions. It must be stressed here that this process, which is a transition from concept to real action, cannot be derived automatically. There is no handy manual applicable to this process. This is one of the most important processes of forming research programmes which aim at answering social wishes. Recently, research programmes supported by governmental budget are often named as issue-driven or problem-oriented, answering people's expectation for scientists to solve difficult problems confronting them. Those programmes, which are described in terms of science, seem to be formed unfortunately rather intuitively and not rigorously followed the process of detailing from macroscopic concepts to microscopic or elaborated scientific actions. We need "science of programme formation" in order to design and develop effective and efficient strategies for scientific and technological research toward innovation.

## 4.2 Several thought experiments

In this section we shall illustrate examples of the intuitive emergence of scientific and technological solutions which satisfy the given social wishes through their elaboration. This is the process of encounter between wish and solution.

Here we aim at conceptually understanding the relation between social wishes and solutions of scientific-technological research programme which satisfy the wishes. We shall show three examples of emerging process of solutions from wishes, none of which is represented in logical manner, but useful for conceptual understanding. This process is analogous to the engineering designing process which appears at designing artefacts such as architecture and machines. In this analogy, the social wish corresponds to requirement of design and the research programme is designed artefact. The design process is known as abduction logically and so it is immediately predicted that there exists no practically possible general method which conducts the programme formation process in systematic manner. The three examples below have no logical basis and do not clearly express the thought process scientifically, but may show the outline of research formation processes which is necessary for further considerations.

**Example 1** Maintaining international competitiveness of the Japanese manufacturing industry in a time of declining birth rates (sustainable industry)

### Social wish

It is recently said internationally that it is a mistake to think that the main supporting economy of a country will follow a transition from manufacturing industry to service industry when she proceeds from a developing to a developed country. Moreover, maintaining competitiveness in manufacturing remains an important task for advanced industrial nations. While developing countries continue to grow their economies as manufacturing states that dominate through low cost, Japan faces unavoidable conditions such as a declining birth rate which leads to an absolute decrease in the labour force as well as high wages, together

with lack of material for manufacturing, needs for the import of energy and food which are all disadvantages for world competition. Therefore, it should be said that Japan must tackle to maintain the manufacturing industry's competitiveness confronting those various difficulties.

### **Postulates**

Japan will keep the following conditions:

- 1) No import of skilled workers from foreign countries
- 2) Design and manufacturing technologies which were grounds for the Japanese economic prosperity in 1970-80 are retained internally in Japanese manufacturing companies

### **Hypotheses**

Those conditions allow us to think that the following ways to preserve international competitiveness are possible:

- 1) Production of advanced products not possible in other countries: products of novel functionality, innovative design, high-level system products, energy conserving products
  - 2) Physical advantages of product: new materials, high-quality raw materials, atomic level surface finish
  - 3) Productivity improvements and high automation level: innovative production technologies, automation of complex assembly, unmanned factory with low-cost robots
- etc

### **Scientific-technological wishes**

The following scientific-technological wishes (scientific-technological research strategies that will realize the social wish) are derived from these hypotheses:

- 1) Development of high-level design methods
- 2) Systems engineering relevant to manufacturing
- 3) New materials such as nano, composite, and bio materials
- 4) Innovative production technologies, such as ultra-high precision machining
- 5) Low-cost and high-efficiency automation such as intelligent robotics for assembly

The aforementioned scenario is illustrated in Figure 21, which explains the transition from social wish to scientific-technological research strategy by using the design theoretical method.

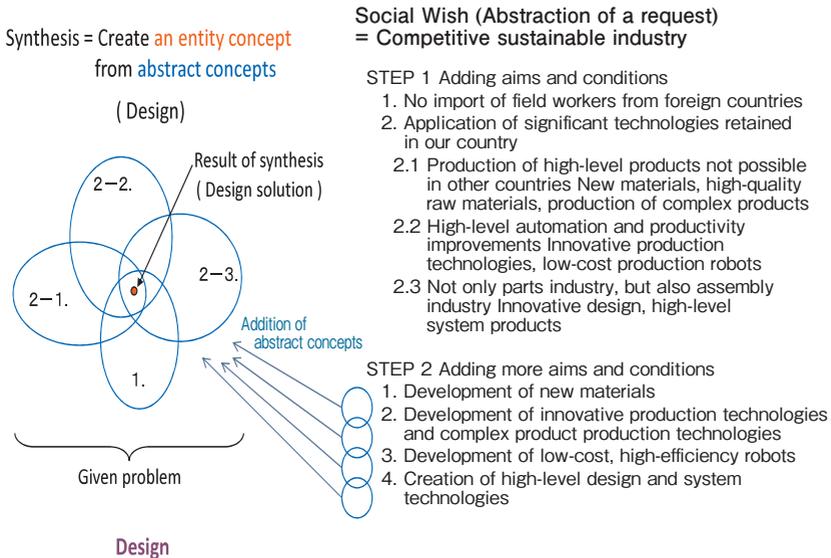


Figure 21 From social wishes to research tasks (illustration of Example 1)

**Example 2** Basic technologies which secure Japanese self-sufficiency in food (food security)

### Social wish

Any states have to secure food for their citizens under any kind of natural change in environment or political change in the international order. As the ultimate method, food security for humankind should be realized as a whole harmoniously through international cooperation. Yet, we are far from reaching the end of this path and apprehensive of a great number of risks before the end. It is necessary, therefore, for Japan to develop a policy to secure the food first for themselves. The basic structure of this problem is the task of providing food security for 100 million people using Japanese nature. In order to solve this problem scientifically, we need to generalize it to find a method of self-sufficiency in food which can be

applied for any country. First, for generalization, it is necessary to think that the method may be affected by various natural factors, such as climate, geology, geography, vegetation, animal species, etc. Needless to say, it will be affected by population and age distribution. Then, based on these natural conditions, scientific-technological research for realizing the self-sufficiency in food will be planned. Unfortunately, such general theory of self-sufficiency in food is not available presently. Therefore, we should look for a special solution for Japan. It is noted here that this solution for Japan is still an extreme case, and international trade of food is practically acceptable.

### **Postulates**

The following conditions apply:

- 1) The population does not increase, the standard of living rises, and the preferences for food do not change.
- 2) Production of food is carried out only domestically without imposing burden on the environment.
- 3) Present numbers of agricultural workers can be maintained.
- 4) The realistic performance of technology follows the international regulations.

### **Hypotheses**

- 1) Practice selective breeding through life sciences  
Plant breeding, seedling cultivation, genetic recombination
- 2) Efficient use of production resources (soil, sun, air, fodder, fertilizer, etc.)  
Agrotechnological innovation of resource use technologies
- 3) Upgrading production means High-level automation of farming operations

### **Scientific-technological wishes**

- 1) Development of environmentally adaptable species (animals, plants, microbes)
- 2) Realization of adaptive agricultural industry structure to natural and social changes
- 3) Development of general-purpose agricultural machines such as mobile robots
- 4) Improvement of the work environment of agricultural workers

**Example 3** Achieving the goal of cutting CO<sub>2</sub> emissions by 25% by 2020 (compared to the 1990 level)

### Social wish

Japanese nation wishes to contribute to sustain the global environment. As for the effort of cutting the emission of CO<sub>2</sub>, people wish to keep the international promise which was declared by the prime minister in an international conference. They feel that keeping the promise is necessary to secure Japan's international status.

### Postulate

The goal has been internationally announced.

### Hypotheses

Research in the field of energy technologies is now intensively conducted, but it seems posing risks to rely only the research in the energy field. Thus all existing technologies should be examined by what research programmes they contribute the CO<sub>2</sub> cutting.

Scenario is complicated including factors political, societal, economic, scientific and technological. We abridge it and only the summary of scientific-technological wishes is shown below.

1) Energy conservation (1)

Improvement of existing energy technologies by the improvement of energy efficiency

2) Energy conservation (2)

New systems design of information network, houses, transportation, etc.

3) Development of renewable energy

Photovoltaic, Solar thermal, wind mill, geothermal, biomass, tidal power, hydrogen technologies (technologies for safe use and hydrogen production)

4) Nuclear power

Essential safety, protection of people from radiation, nuclear fuel cycle, new fuel disposal regulations

5) Development of new utilization of energy

Small hydroelectric power, geothermal use by households, energy collection, energy recycling

6) Carbon sequestration

It becomes clear from these experiments that a solution intuitively comes to mind at some point while the elaboration of wishes progresses. This makes it possible to accept as true the prediction that the elaboration process of social wishes has a nature similar to design: the quality of solution (research programme) improves the more, a designer(planner) expresses the requirement (social wish) using the more functions. When a designer rushes to find available scientific-technological solutions, the quality of solutions ought to become far from the optimum.

Figure 22 shows, using Example 1, that it is possible to represent this process as a mapping model of general design theory. In this case, the social wish is the improvement of competitiveness. The figure shows that the quality of the social wish improves by applying the additional social wishes to the initial one, which might be generated through the process of elaboration of the initial wish. This corresponds to a theorem of general design theory [15] which says that the quality of solution approaches to the optimum as the specification of design requirement gets narrower in the function space. This explains the phenomenon seen in the above example where people do not find a concrete solution when thinking about a scenario in high abstraction level of wish, but a concrete image comes out suddenly when they add up relevant independent additive wishes.

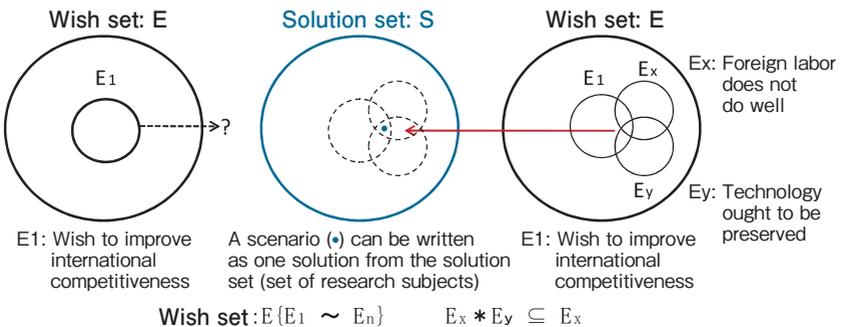


Figure 22 Example 1 expressed through the set theory of design science

### 4.3 Importance of strategy design as the first step in research

As seen in the preceding discussion that the process of transition from social wish to research strategy or scientific-technological research programme seems to be included in the category of general design where design scientists have not yet been successful to construct a universal method of design, we should abandon an easy expectation to develop a scientifically universal method for the present process. However, at the Centre for Research and Development Strategy (CRDS), we need some guiding principles for our work that is formation of research strategy for various social wishes. They may be not the scientific-theoretical method but could be useful practically. We need extract common knowledge useful to derive those principles by recording and analysing repetitive works of programme formation. Through this effort of knowledge extraction, we have realized that this process is a very specific phase of scientific research because this process which is to be carried out in panoramic or discipline-free view cannot be conducted by normal disciplinary researchers. We may say that this is a specific research area which is the first step of research programme and can be called the research on "discovery and analysis of social wish". This kind for research will be carried out by CRDS researchers who are scientists not concerning themselves about specified disciplines.

Let us now discuss in more detail that the quality of solution is dependent on the location of transition point on the process from wish to solution..

The process of deriving scientific-technological research programmes i.e. research proposals from conceptually mentioned social wishes is a kind of design; that is, the thought process and the procedure are synthetic as design. As there is no authorized systematic technique based on the science of synthetic thought process, thought process of synthesis often takes the form of an essay and consequently the legitimacy of the conclusion cannot be assured objectiveness.

However, designing or synthetic thought process is by no means driven simply by chain of fortuity because designer's ability to produce a

correct or high quality solution is surely improved by repetitive works or proficiency. Even if it is not yet known, there certainly should be a systematic method. Therefore, in real design shops, practical experience is an effective strategy for individual proficiency, such as repeating the design process, recognizing it and recording it as objectively as possible. However, CRDS is composed of a group of professionals who cooperatively derive the research strategies. It is desirable to describe those experiences explicitly in order to share the recognition and recording of these processes among them and to accumulate continuously the common knowledge to be used in the following works in the institution.

In order to find out the reason of the fact that the quality of the solution changes depending on the location of transition point, it is necessary to think not only about the stage where research strategy is decided, but also about the whole flow of research activity. Figure 23 is a simple illustration of this flow. After a research strategy is derived from a social wish, researchers make a research plan according to the strategy, implement the plan, conduct the research and when they accomplish the research obtaining novel knowledge, then they publish the results to society as scientific papers. The strategy normally includes two phases: analytical research by theory and experiment and constructive research by design. Then, actors in society use the results aiming at producing innovation. When they accomplish successful innovation, the results of scientific-technological research will spread and diffuse into society being carried by innovations. This diffusion of new knowledge is probable to produce new social wishes which become the new target of discovery. This is exactly the circulatory system of evolution already mentioned in the preceding chapter. The same figure shows an example of bioenergy. In this case, however, the diffusion creates a conflict with the problem of food supply which is a subject in a field absolutely different from energy issue. The emergence of new social wish is often observed in unrelated field. Therefore, new research strategy to avoid such problem may be within the same research field or else.

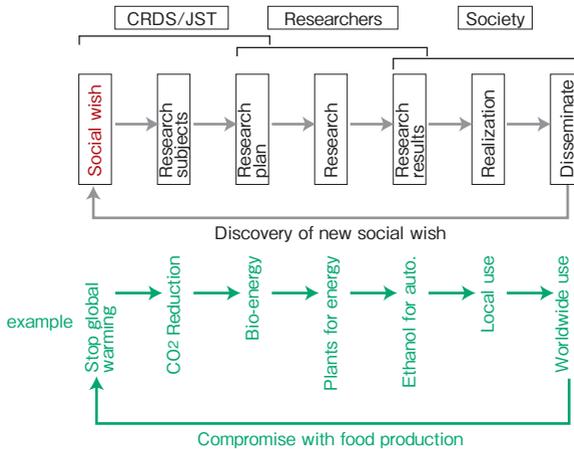


Figure 23 Flow of research targeting social wishes

Figure 24 shows the people involved in the research process who construct a loop similar to the one in Figure 23. Here is a question who are to be called scientific researchers among those people. While people designated researchers in this figure are named researchers in a narrow sense of the word tentatively here, we shall discuss this later and will expand the definition wider because most of them are participating actively in research.

When researchers, in the narrow definition, write a research plan in the third block of the Figure 24, the transition from social wish to research strategy has been already finished and the describing words have turned into words of science. Therefore, the transition must occur between social wishes and research plan, namely between the two left transitions designated by arrows. If it occurs in the second transition that is on the arrow between research topics (second block) to research plan (third block), the transition should be as follows. Organizations distributing research funds to researchers, which are called funding councils (like the Japan Society of Promoting Science(JSPS) or the Japan Science and Technology Agency (JST)), appeal for research by announcing social

wishes in the words of society. Then researchers independently invent the research programme with the possibility of satisfying the wish. Then they propose it as a research plan. As an example, when the social wish is to preserve biological diversity, founding councils are allowed to say only this, without any suggestion of scientific-technological means to do the research. Scientists from all disciplines then would probably present various proposals. In this method researchers can freely construct research programme answering the wish. Therefore, from the viewpoint of maintaining the fundamental principles of basic research, it can be called a right way because it protects the research autonomy from outside pressures.

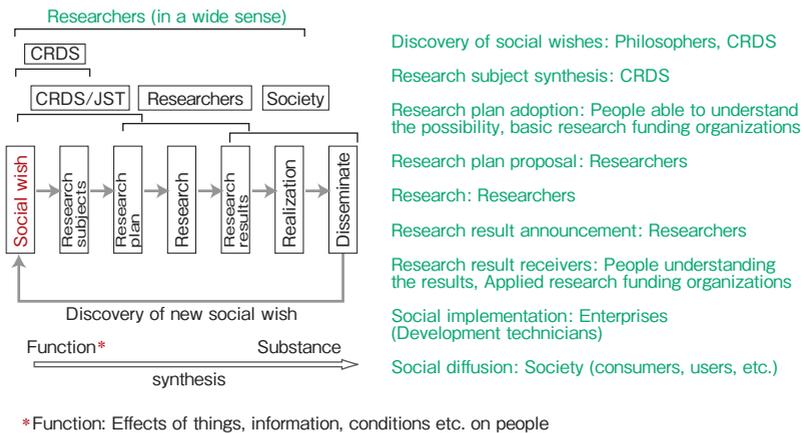


Figure 24 Researchers (in a wide sense) participating in research targeting social wishes

However, even though this method is possible for as small-sized research subjects as individual researchers can independently form research programme, an overhead trans-disciplinary viewpoint is needed for large-scale research subjects with public research funds which attract wider social interest with expectations of a large social effect. In the case where a large number of and diversified factors must be considered to form a

research strategy, we need collaboration and coordination among scientists of different disciplines. This kind of research normally needs consideration of the status of seemingly unrelated academic disciplines and the development of various academic disciplines in future where an individual researcher is not up to the job. Therefore, it becomes necessary that the transition from wish to scientific solution must occur in the first transition which corresponds to the leftmost arrow in Figure 24. To find the optimal solution, This means that the transition must take place on the way to creating research programme and within the process of research and development strategy. As the mission of CRDS is to develop research and development strategy, it also carries the responsibility for the transition. Therefore, the work of constructing research development strategy that we conduct at CRDS should be an important part of research activity. In other words, the work of CRDS is the very first phase of the research programme.

## 4.4 An example of elaboration of social wish

Some rough sketches of process of transition from social wish to research strategy were shown in the preceding chapter. Here, the more detail of this process will be shown and analysed again by an example. The detailed process include the process of expression of a social wish, consideration of prerequisites and conditions for the wish, discovering new social wishes accompanying the initial wish at different levels, creating a scenario to satisfy those social wishes and reaching the final expression of elaborated social wishes which encounter research strategy in science and technology. This elaborating process is effective in discovering new invisible social wishes (e.g. science of change and altruism).

In the thought experiment, we have experienced that scientific-technological knowledge that has the possibility to satisfy the wish suddenly appears when the elaboration progress to some point. However, it is just an empirical fact and does not suggest any scientific ground behind the appearance. It seems impossible to achieve a scientific-technological solution to the wish as long as social wishes are elaborated within the words of society. It might be achieved intuitively, but this procedure cannot be written down in a scientifically fixed form. To do this, one has to wait until a stage where even the words expressing scientific-technological programme are changed. This means that both sides need to move closer for an encounter, so the elaboration of wish is only a necessary condition of the encounter. The approach to the encounter from science will be discussed in the next chapter, and here an example of elaboration of a wish by the author himself will be introduced while taking the characteristics of social wishes as the basis.

Social wishes are diverse and complex but there are necessary conditions for them to be socially accepted. First, wishes with arbitrariness, harm and self-righteousness are by no means allowed. Secondly, the wish must have potential possibility to be expressed by the words of science. Our experience taught us that the elaboration is done in the more precise words of society the quality of the solution improves the more. Here, we

try to follow this experience in developing an example.

What has become clear until now is that (1) social wishes are diverse, (2) social wishes have levels, (3) when social wishes are expressed in the words of science or technology from the beginning, most of them are local wishes with no widespread diffusion through society, and consequently social wishes should be expressed as much as possible in the words of society, i.e. word expressing functionality, (4) wishes including many independent functions seem to make it easier to derive a solution (by intuition in a thought experiment), (5) the transition from wish to solution occurs in the process of formation of research programmes and (6) the research programme planners take an important part in the information cycle driven by research which were described in the preceding chapter. Thus, the following process is the elaboration of given initial wish into one which will be bridged to research plans or policy proposals. Research plans and policy proposals written in the words of science are sometimes called "scientific wishes" which are transformed from social wishes.

The example below shows an experimental work by the author. First, a social wish is discovered, and its elaboration follows, by which the initial wish is transformed into one that can transit to the research plans and policy proposals written in words of science. The process is described below. A social wish here was represented by a hypothetical scenario created by design methodology and synthetic thinking, and the process of deriving the research plans and policy proposals is also done by design methodology and synthetic thinking.

#### **A procedure:**

- Expression of a primitive social wish
- Enumeration of prerequisites and conditions connected to the targeted wish but given and not possible to change by policy
- Discovery of the social wish at different levels by survey and analysis
- Writing a scenario which satisfies the social wish by hypothetical abduction and analysis

- Elaborating the social wish for final expression to make the transition into words of science by abduction

### (1) Expression of primitive social wish

In order to continue contributing work internationally toward improving global sustainability and concurrently protecting Japanese wealth and culture under this quickly changing international environment including rapidly growing newly industrialized nations, we necessitates to invent our original activity different from the past by using science and technology. We wish to be such a sustainable country which emphasizes science and technology.

### (2) Prerequisites and conditions

a. Request: The world is in an unprecedented situation with a growing population and expanding economy but also confronted with scarcity of energy and resources, and the problem of environmental degradation. In the midst of this, Japan has a declining birth rate and will shrink from a nation with 10% at present of the world's economy to a nation with 3 % in near future. It is necessary, therefore, to recognize Japan will be placed in a global position different from its current situation in the viewpoint of international cooperation, while all nations in the world are aiming at constructing sustainable world cooperatively. Here, we shall hypothetically propose a desirable image of Japan in future as follows: Japan will grow into a country which contributes to improve the world sustainability and concurrently maintain own economic security. For this realisation, Japan will need more intelligent people who confront inexperienced difficulties newly emerging worldwide in future. Japanese society shall become a space where people improve their intelligence, not only at schools and universities but at any workplaces through their everyday studies and works. Then, Japan will have more thinkers in various sectors who confront coming difficulties in particular sectors. Practically, we shall educate large number of new researchers, the definition of which will be mentioned later.

b. Present condition: The work incentive of young people in a country

that has become wealthy is not to try to become even wealthier. Quite the contrary, as long as the certain level of living standard is maintained, their wishes are to find works they are interested in, to have freedom in interpersonal relationships and to engage in work without being tied to an organization. Researchers are one of these types.

- c. Japanese achievements: Japan has a history of creating good numbers of positions for advanced researchers in universities, research institutes, public organizations and enterprises, and the international level is high in certain specific disciplines.

### (3) Modern social wishes by level

#### a. Essential conditions:

- Expansion of employment: adequate numbers of occupation of various types preferred by people are provided socially and people have chances to get preferable jobs.
- Industrial competitiveness: Industry has high competitiveness internationally by sustainability-compatible products and services based on basic research.
- Sustainability: Reduction of greenhouse gas by 25% (international declaration)

#### b. Stated wishes = Demands already identified in society

- Occupation: Sufficient employment through diverse types satisfying the diversifying wishes of young people is urgently requested.
- Life: Secure lives which will not be disturbed by outside condition are normal wish among normal people.
- Sustainability: People agreed to contribute socially and personally to confront various problems such as climate change, adaption to changes, preserve of biological diversity, water control and transition from fossil to renewable energy, energy saving.

#### c. Invisible wishes = Social questions (problems undetected or spreading while recognized only vaguely)

- Values: People feel the limit of present values and look for a change which is not known.
- Competition: Hard competition of entrance examination for

universities, superheated priority competition of scientific research and exaggerated competition among new products of companies are almost useless for healthy improvement of society. People wish to moderate them, but do not know how to do.

- Society: People have vague concerns about the future of Japanese society because of many important factors have been left unimproved such as correct valuation of ability, clarification of authority and responsibilities, defeat of social petrification, improvement of transparency of governmental administration etc.

#### **(4) Hypothetical scenario: "Researchers in the future"**

##### **Basic direction**

- a. Enhancement of human talent: Number of researchers will be increased, and at the same time it is essential to find potential researchers who have research oriented talent but unconscious.
- b. Change of main industry: New enterprises utilizing new knowledge created by researchers will take a central role in Japanese economy. Industrial structure will also change because of the shift of main products to goods and services compatible with sustainability.

##### **New researchers**

- a. Numbers: Research positions in education and research organisations, and in industries will be remarkably increased.
- b. Career: The educational and professional paths on which young people become researchers are to be diversified. Also it is necessary to improve social and economic treatment of researchers.
- c. Redefinition of researchers: By present definition of researcher, people are covered who conduct research at universities and research institutes, and write research papers. The research, however, is supported by various people who are not presently included in the definition. Without those people, no research can exist. Therefore, it is logically necessary to extend the definition of researchers. The extended definition covers people think logically to create something new. The new researchers are observing or analytical basic researchers, designing or planning basic researchers, research implementers (who have been traditionally called researchers), and

further research strategy proposal planners, think-tankers, research fund distributors, practitioners who use research results, design engineers, educators, entrepreneurs, etc. All of them are closely connected to research and play important roles to direct and drive the development of science and technology although they do not write disciplinary scientific research papers. They are illustrated in Figure 25, which shows the mutual relationship.

- d. Continuing employment structure: The extended researchers involve various occupations, some of which are mutually related and easy for employees to move from one to another. It should be noted here that the move of people becomes easy not only within the extended researchers but also through "borders" between researchers and other occupations in society, because some occupation of extended researcher such as engineers and practitioners have close commonality in disciplines. By creating such a social structure with easy movement from researchers to non-researchers in accordance with the extended occupational definition, the mobility of intelligent people will be improved, hence accomplishing the right human in right job for them. This hopefully assures that the occupation of research will become less special in society and attractive for young people who have potential intelligence.
- e. Education system: It is necessary to creating a diverse and broad system for the education of new researchers not only in education and research organizations, but also within industry. It is aimed that all occupations will have educational functions.
- f. Social set of career paths: In order to realize the aforementioned system, it is essential to provide new researchers with flexible career paths where changes among occupations do not lead to their losses. This must be realized by a policy, but the change of mind set of adult professors and research managers are strongly requested.

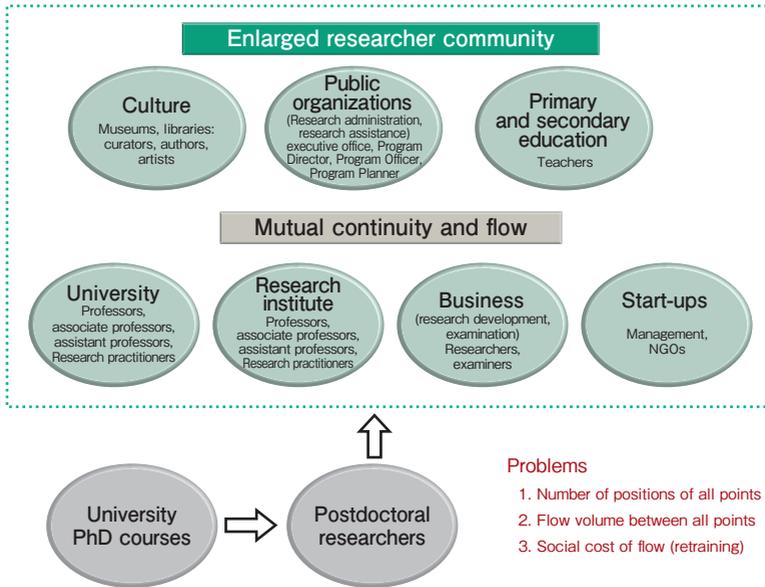


Figure 25 Extension of researchers and continuing occupational structure (career structuring strategy, flow acceleration strategy)

### (5) Transition to scientific wishes

It can be said that social wishes are considerably elaborated by analysis and design, but can they at this stage be written as scientific wishes corresponding to the social wishes? Looking at the scenario we made, the following items are included: new industry, change of industry structure, sustainable technology, sustainability-compatible goods and services, increase of researchers, redefinition of researchers, structures formed by new researchers and continuous occupation structure. Every single one is still functional or written in words of society, and far from the scientific wishes. But when social wishes are accumulated according to the way of thinking shown in Figure 22, it can be said that the possibility of entering at the world of science has increased. The work of entering is the subject of coming chapter and not discussed here, but the elaboration of social wishes following the above mentioned procedure is observed to be effective for the transition of social wishes to scientific wishes.

Here, we shall consider an important function immanent to this method, namely the function that gives us chances to notice new social wishes through elaboration. Namely the elaboration is useful for the discovery of invisible social wishes.

A common element is identified among the diversified terms extracted from the scenario. It is "change". Change is not a novel concept among us because we everyday keep calling for reformation in all sectors of society. We are sick of hearing university reformation. And on the other hand, we are tired of reformation and our true feeling is to resist change. There is almost no practically useful effort to tackle changes straight on, and neither is there research programmes aiming at acquisition of necessary knowledge for reformation.

While tackling the elaboration of the present social wish, we have reached a concept "change" seemingly important for the goal to be expressed in word of science. Then, it should be our obligation to notify the necessity to develop "science of change" as one of fields of basic science.

By considering this issue, we reach a tentative solution as follows. In the beginning of this scenario, a prerequisite was given such that Japan will inevitably become a relatively small country by 2050, but wish is to remain an advanced country that continues international contribution and keeps good economy. In order to harmonize these two; prerequisite and wish, it is obvious that Japan should continue changes in coming years until 2050. In other words, changes should occur constantly. Constant change becomes the central importance for Japan. In coming years, industry, including its products, management, form of business, structure workers, changes as well as politics, administration, education, medical systems, welfare and so on. All systems change and consequently urge the alteration of roles of people. If such successive changes in many sectors are estimated to occur constantly in a society, we cannot avoid considering if a society can be stable with such constant changes.

First, let us examine a question whether a change can produce mutual benefit or conflict and strife. Changes include the following, from the left to the right of each line:

- Traditional large corporations → Start-up companies
- Material manufacturing industry → Function creating industry
- Research discipline A → Research discipline B
- Mass education → Education of small numbers of people
- One-directional media → Interactive/dialogue media
- Developing science → Sustainability science
- Young researchers as human resources → Young researchers as treasure in society
- Imitating society → Self-organized society
- Divided independent research → Network cooperative research
- Conflict about resources (including negative ones) → Joint ownership of resources (example: CO<sub>2</sub>)

As seen, there are uncountable examples. As the example of industrial change in Figure 26 shows, change does not occur discretely but constantly, little by little over time, in other words, "incrementally". This is the reason why change becomes constant. When thinking of the transition from traditional large corporations to start-ups as an industrial change in real society, it becomes immediately clear that the change is not an easy matter. It is said that the difficulty of such change here is one of Japan problems which are tough to overcome. The difficulty seems due to various factors caused by characteristics of Japanese tradition. Those characteristics may emerge as following phenomena which make a bad scenario for Japanese industry in future hopefully to be avoided:

- Traditional corporations regard start-ups (ventures) of the similar fields as hostility and compete against them.
- Social sensitivity to the necessity of change of industrial structure corresponding to the change of society either domestic or international is low.
- In such situation, private investment in the creation of start-ups is not

increasing.

- Thus, ecology for birth of new business does not grow well and the chance to initiate start-ups cannot improve, and the start-up success percentage remains low.
- Because of such trends of whole industry to remain as they are under such condition, international competitiveness falls and the economy stagnates. Consequently Japanese industry will be confronted with less and less possibility to change.

If this vicious cycle is not resolved, our country will not live well through the age of change and the economy will not be revived. Therefore, the developments below must occur.

- Traditional corporations welcome new start-ups.
- This trend decreases the risk of failure of start-ups and induces the increase of investment.
- The start-up success level rises.
- Then, start-ups attract private capital hence increase of total investment to them.
- Owing to the success of science based start-ups, transformation of basic science to useful technology is accelerated in industry, and consequently the international competitiveness of Japanese industry improves. This can be a way for Japan to rebound its economy and concurrently secure development of traditional corporations

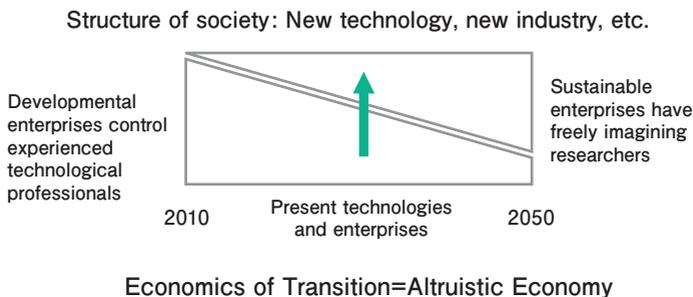


Figure 26 Incremental change in industry (Economics of change)

This is a positive cycle.

As is understood from this example, it is quite possible that an alteration of main actors accompanying a change brings benefits to both actors without perishing one who passes. However, in reality, most cases have not turned out this way. Instead a short sighted perspective leads to perceiving contradictions and personal disadvantage, and thus to opposing change. As a result, the "cost of change" rises. One could think that Japan might be trapped in this kind of situation. Then, how can we escape from the trap?

"Altruism" is the key for escapade. Ill perspective comes from a premise that any change produces a loser with big damage. In this case, competition is driven by antagonism where competitors compete on the basis of egoism. But as widely said, competition is often a useful tool for the concurrent improvement of both competitors, in spite of win or loss. Altruism has been discussed in many academic disciplines but without touching those discussions, the altruism is simply thought here that a member of a community acts for the benefit of other members of the same community to ensure the survival of the community. Figure 27 shows examples of change in the leading role. When one of the items in the left column changes to a new subject, the current leading actor is assumed to exchange place with the supporting actor. If at that point their relation turns into conflict, the community must pay the cost without benefit for the internal friction caused in the community. Let us consider an example of competitive funding for research. If a research group in a community that attracts the most attention eliminates its rivals just to maintain its status, or a competitive funding system supports only this group and abandons the others, then the research programme will refuse participation of certain number of potential researchers in this community, therefore producing research results far below the highest possibility of the community. If we trace this way, Japanese research will be defeated in the international competition as a whole, even if we have some peaks of world advantage in limited research areas. And thus it is probable that our efficiency of funding or results per fund as a whole becomes inferior. We must learn from this case that a funding that selects a single researcher

and kills others causes long term inefficiency of funding. Instead, we need a funding to a relevant network including competitors. Now, we should realize that there is no room for competition of the kind that creates internal friction in our country.

When we regard the changes shown at Figure 27 as social wishes, we immediately find many of those changes could be accomplished by scientific-technological means. In other words, it is necessary to form scientific-technological research programmes to induce those changes. If the elaboration of social wishes is advanced, many partial wishes will be discovered. Some of these partial wish become possible to be translated into scientific wish which is written in words of science. Such individual partial wish reminds us of a specific scientific-technological discipline, including humanities, social sciences, life sciences and physical science, suggesting their characteristic transition from wish to science. The elaboration of social wishes, in this way, enumerates the necessary transitions. The subject of the next chapter is to examine what kind of expression is necessary on the side of science to actually make the transitions, in order to realize the encounter.

| Themes                          | Subject (Others)            | Others (Subject)           |
|---------------------------------|-----------------------------|----------------------------|
| Science for society             | Analytic researchers        | Designing researchers      |
| Science for sustainability      | Developmental science       | Sustainability science     |
| Network research                | Isolated schools            | Other schools              |
| Panoramic view                  | Own academic discipline     | Other academic disciplines |
| World stabilization             | Advanced industrial nations | Developing countries       |
| Sustained biodiversity          | Humans                      | Other living things        |
| Focus on natural environment    | City                        | Rural villages             |
| Resource sharing                | Owners                      | Non-owners                 |
| Internationalization            | Japanese                    | Foreigners                 |
| Generation change               | Adults                      | Youth                      |
| Decentralization of power       | Center                      | Regions                    |
| Industrial change               | Traditional corporations    | Start-ups                  |
| Evolution of industry structure | Manufacturing industry      | Service industry           |

Figure 27 Altruistic society realising sustainability (Altruism)

The cooperation between observing scientists and designing scientists is important because the link between observing science and designing science is operationally essential to accomplish innovations. Cooperation of both scientists is, however, difficult because they normally belong to different sectors in society, and moreover the attitude regarding research and methods of thought are different between them. We shall introduce here the way a method called Full Research, aiming at implementing this cooperation as well as constructing a well-shaped information cycle mentioned in the preceding chapter. In full research, two integrations are requisite: one is an integration of disciplines by combining knowledge of diversely specified domains necessary even within a discipline and another is integration of roles of scientists such as observing, designing and producing, normally conducted independently. In the present case, in order to realize the encounter, elaboration of scientific-technological knowledge is concurrently requested as the elaboration of social wishes through functions is going on. The encounter will occur through approaches from both sides.

Here, we introduce a new concept which is called minimum functional network. It is a network of research, i.e. of researchers or research topics; which produces a result exerting a certain function recognisable in society. Elementary research included in the network is conducted within one or a few disciplines and selects a role. For example, a research on identification of properties of new materials such as carbon nanotube is driven in the disciplines of physical theory of carbon, physical theory of crystallisation, quantum theory of nanomaterial, electron-microscopic observation technique etc., and the role is analysis or observation. When the research creates a novel knowledge about behaviour of electrons within nano-scale space, and even if the result is highly applauded in special scientific field because of its novelty, the result has only possibility of use in society, and society does not receive any practical benefit directly from the result. However, if new results of different researches are added to the initial result, the integration of those pieces of knowledge will exert functions meaningful in society. In this case, the different researches are mass production technique of carbon nanotube, accurate shaping of bundle of tubes, control of electron mobility in tubes etc. Each of them belongs

to different scientific disciplines. Therefore, the function recognisable in society can be achieved only when relevant research topics in different disciplines are combined in right way. We call this relevant combination of research topics as functional network of research. Minimum functional network is one which will lose its function when it is divided.

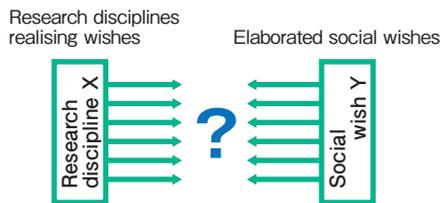
The minimum functional network is written in word of function or society although components of the network are written in word of science. We may thus hope that the encounter of social wish and scientific research strategy becomes realistic through this networking. Actually, if we successfully make a panoramic view or databases of social wish and of minimum functional network independently, we shall have chances to discover an encounter by their comparison. Further, by comparing the panoramic views of social wishes, of observing research and of designing research composed of functional minimum networks, possible full researches will be extracted by connecting them to create a sustainable loop in the preceding chapter.

The creation of a structured panoramic view reveals the relevant composition of full research which derives a new type of innovation based on holistic observation. It is an important research system in the age of sustainability. The structured panoramic view is an effective method for making proposals of research strategy.

Let us consider creating a panoramic view of research topics which conforms to the elaborated social wishes discussed in Chapters 3 and 4. From the standpoint of scientific research, the scientific wishes written in word of science are research development strategies (at CRDS) or research plans (for researchers). There is a new task here to select research disciplines relevant to implement them. It is expected that research is conducted in these disciplines and as a result, fulfils social wishes. Incidentally, we remember that each social wish is not immediately connected to specific research disciplines, even though it is elaborated as much as possible, as described in earlier chapters. On the other hand,

research disciplines as a factor in the panoramic view of disciplines could not be directly connected to social wishes. Therefore, Figure 20 must be redrawn as Figure 28 where research disciplines approach nearer to social wishes. The disciplines also must be reformed or reconstructed so as to conform to social wishes.

Here, we shall proceed the consideration into encounter using the cyclic structure, i.e. loop, for sustainable evolution in which scientists participate. The loop was shown in Chapter 1 Figure 2 and in Chapter 2 Figures 14–17 where roles of scientists and their cooperation were discussed. As described there, it was well expected that driving the circulation of necessary information in the loop is difficult only by efforts to allocate existing research disciplines to social wishes, because of lack of systematic methods necessary to drive the circulation, such as "holistic observation" by observing scientists, the "designing thought" overcoming disciplines that is necessary when designing scientists give useful advices to actors in society. Therefore, it is necessary here to find a method to solve these difficulties while referring to elaborated social wishes.



When social wishes are elaborated, research disciplines also have to be redesigned

Figure 28 Research approaching elaborated social wishes

In order to realize the encounter where conformity between social wish and research programme is established, the following two points must be satisfied practically.

1. Desirable cooperation among the three blocks in the loop: observing

researcher, designing researcher and actors in society.

2. Establishment of a method that can operate scientific concepts consistently through several disciplines, namely creating preliminary disciplines, or special purpose "working discipline" by the integration of these disciplines

This is nothing else than the restoration of indigenous knowledge mentioned in Chapter 1.

We have understood that indigenous knowledge can be split into factual knowledge, knowledge of usage and knowledge of meaning as seen in Figure 10, and each of these can be further divided into disciplines through abstraction by specific interests. Generally, their restoration is composed of two integrations: integration of disciplines and of roles as shown in Figure 29. However, this restoration procedure is by no means simple. We do have neither theoretical method to be applied, nor empirically obtained method which stands diversified tasks in synthesis.

The difficulty in the synthesis of roles lies in the fact that the factual knowledge and knowledge of usage granting meaning are produced by different processes. Factual knowledge is a knowledge system obtained through understanding the existing matters by observing scientists. The understanding is normally gained through "analysis" which follows a process from facts to the scientific laws behind the phenomenological observation of facts. On the other hand, knowledge of usage is that accumulated by repetition of various designs by design scientists who use knowledge which is systematic scientific knowledge gained as a result of analysis, and this is called "synthesis" which follows a process from groups of scientific laws to facts. This relationship is shown in Figure 30.

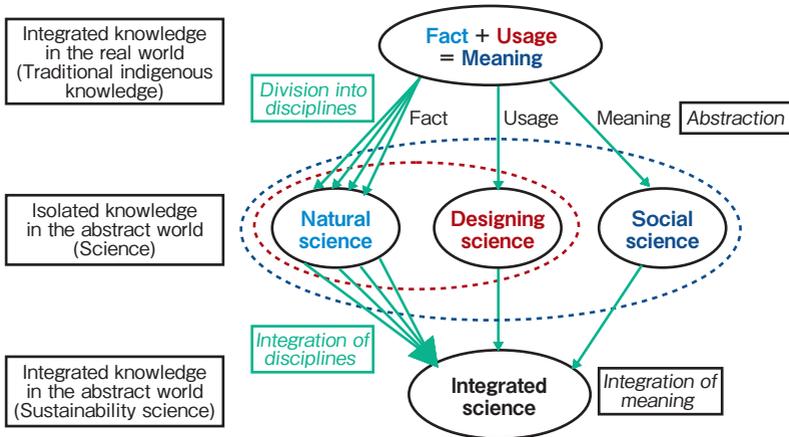


Figure 29 Knowledge integration: Integration of meaning and Integration of disciplines

The analysis in observation is to understand an object by confirming a value of particular property. Increase of number of property deepens the understanding. In case where established disciplines exist corresponding to the property, the object can be analysed and understood using systematic methods supplied by particular discipline. For example, when we wish to know the shape of an object, geometry and methodology to measure the shape are available as established disciplines. For objects which cannot be treated by existing disciplines, some hypothetical disciplines need to be established and then theoretical analysis becomes possible by them. For example, new subjects such as origin of life and long-term climate change, disciplines and measuring methods have to be created as hypotheses, and the validity of the hypotheses increases certainty through the consistency of theoretical analysis and experiment results. If inconsistencies arise, the hypothesis will be rejected. The analytical method that is the main method of observing scientists has gained objectivity by eliminating subjectivity, and now it is a standard method accredited in modern science. Following the claim by Peirce given in Chapter 2 Figure 12, academic disciplines based on analysis become the more systematic, the more abstraction level grows: following the sequence of descriptive science, categorizing science,

nomological science and finally reaches mathematics which can be applied to analyse any subject.

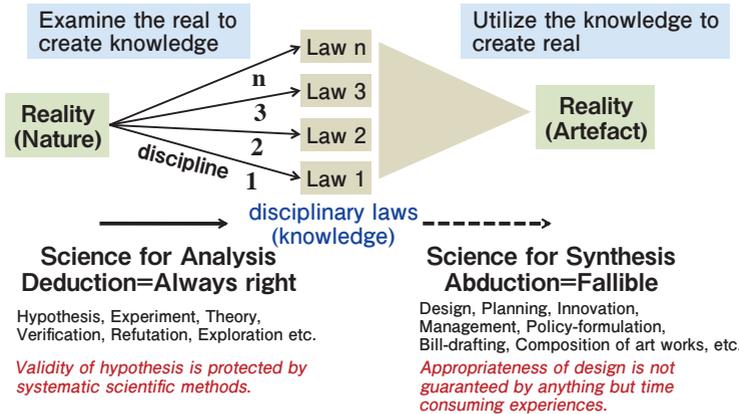


Figure 30 Analysis/Synthesis : Asymmetry of Human Thought

An important point must be mentioned here. It is a fact that once a discipline arrives at the nomological level, then a systematic method becomes available for calculation or logical inference between elements within the discipline. In the case of mechanics for example, which is a typical nomological science, the initial conditions of throwing a body necessary to realize a given trajectory flying in vacuum can be rigorously "designed" by a simple calculation. But this design ability is limited to the subjects within the discipline and if other factors are to be considered like launching a rocket, the calculation will become by far complicated with approximations.

On the other hand, with the synthetic process in design, there is no effective discipline which supplies effective method of calculation to obtain likely design results except for special examples such as strength of material and electric circuit theory. Generally, design is actually promoted by creating disciplines that should be called "minimum disciplines", which is a kind of preliminary disciplines, only applicable to assigned subjects.

Although these disciplines have no socially certified methods for describing and processing objects generally, they are useful for immediate works.

In cases where many disciplines are necessary, a design from scientific laws to facts is performed by creating a preliminary discipline. However, preliminary disciplines that include many disciplines are, according to Peirce, presumably only at the level of description. As descriptive science has no designing ability as a systematic process, designers introduce "individual principles" such as operation hypothesis creating tentatively working disciplines apparently in the form of quasi-sciences which include some variables and definite relations among them. In such disciplines, although variables are specific and have no commonality to those of established scientific disciplines, calculation using these variables is useful to design in quantitative way. These are the minimum disciplines possessing the principles discussed above. However, as the principles are not scientifically accredited, and therefore suitability of the results to the given requirements is not scientifically confirmed, so the goodness of designed results is left for society to judge. It is often said that designing scientists lack consistency when compared to observing scientists, and moreover that they rely on designer's intuition without scientific rules, designing science is only "applied" science that cannot be called independent science and must rely on observing science as a guide. However, as seen above, design is an essentially different action from observation and they are mutually independent. As is clear in Figure 30 and the following explanation of observation and design, both constitute basic research using a completely different style of thought based on different theories. Here, observing research is called Type-I basic research and designing research Type- II basic research. Especially when thinking about innovation, there also is research that spreads innovation in society by some of the actors, which is called product realization. Below, mainly the cooperation of Type-I and Type-II research is discussed.

The cooperation between researches with different roles is necessary to drive the cycle for the evolution of sustainability, but it is not easy

because the logics of their thoughts are different and the disciplines used have different abstraction level and the procedures. The main work of observing scientists is analysis, where the research results can contain description, categorization and laws, and the validity in every case can be examined within the research community of the same discipline. For designing scientists, however, their main work is the synthesis using many disciplines, and an examination of the work results is not possible. The work is even based on the ideas of individuals, or abduction in terms of logic. These differences separate the research attitude of the two types and lower the possibility of dialogue. As a result, the two have formed different communities such as departments of science and engineering in universities, and collaboration does seldom happen. The observing scientists unilaterally send out their research results and the designing scientists select from these at their convenience and use them as the basis of design, which simply leads to poor cooperation. This is the reason behind the separation illustrated in Chapter 2 Figure 6 where the connection between the two is unilateral and arbitrary.

No suitable cycle can be achieved in this separate way. Therefore, full research has been proposed [6] to eliminate the separation. It can be visualized as seen in Figure 31. Full research is defined as "research for innovation by designing researcher on the basis of new scientific knowledge gained by observing researcher". If we go back to Chapter 1 Figure 2 and think about the cyclic structure for sustainable evolution, cooperation is essential for the three participating parties—observing scientists (Type-I basic research), designing scientists (Type-II basic research) and actors in society receiving their scientific advices and actually trying to improve nature and society (product realization). Such research where they progress together, sharing the same aim, is full research.

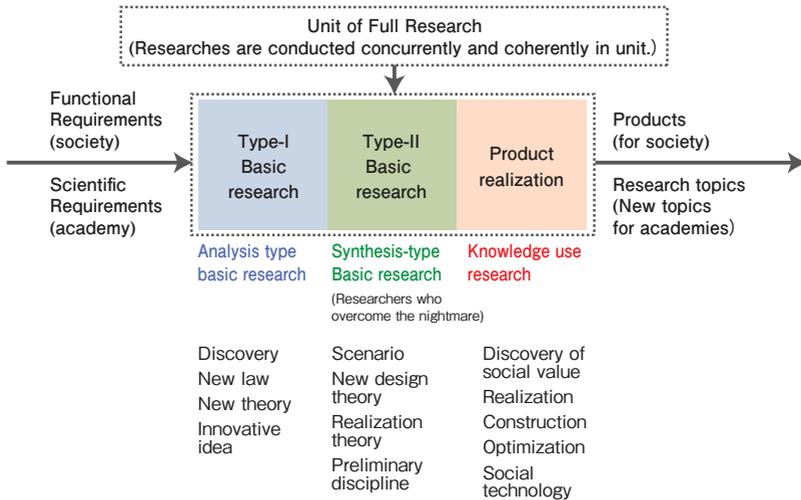


Figure 31 Full Research for Social Wish

What is cooperation of these different researchers? Full research essentially is one form of thought process. As expressed before, this is a thought process aimed at satisfying social wishes where the following thoughts happen in analysis and synthesis without raising inconsistencies: the exploration of diversified disciplines that seem to be useful to satisfy given subjects such as social wishes, analysis based on the process of hypothesis, experiments and validation in these disciplines, hypothetical creation of preliminary work disciplines by synthesizing the knowledge gained through analysis, design in those preliminary disciplines, discovery of lacking knowledge, addition of disciplines etc. and their repetitions.

Above procedure can be done by one researcher. But normally, such procedure requires many kinds of disciplinary knowledge and various experienced thinking methods, so if one researcher be engaged in it, one must be a superhuman. Therefore, many researchers must participate in a full research programme and cooperate within it. When a full research programme is to implement, the conditions outlined below are necessary.

1. There are researchers whose specialisation respectively corresponds to all scientific disciplines necessary for conducting the full research.
2. There are researchers of the three types of roles (Type-I and Type-II basic research, product realization) for every discipline.
3. A common language is available between researchers of different disciplines and of three types of research.
4. The three types of research are not conducted sequentially but done concurrently and coherently.
5. Researchers can move between the three types of research.
6. Researchers in full research programmes share the target to be achieved.
7. Full research requests its supervisor to be a superhuman or at least one who knows what superhuman means.

In general, the organizational units of research in universities and research institutes do not fulfil these conditions. In most cases at unit-like organizations such as institutes, laboratories, research units, research divisions, of university and corporations, a research group is normally organized with only single scientific discipline and only one role. Research subjects are numerous and various even within a discipline, and the supervisor is not a superhuman, so the above criteria are usually not fulfilled. Therefore, they cannot indicate their own roles in the loop for sustainable evolution clearly and their place in cooperating network is also not clear. As a consequence, when such an organization tries to achieve innovation, researchers will be confronted with unexpected problems even when the level of researcher's ability is considerably high.

Even if realizing innovation is difficult for these unit-like organizations on their own, it works if many organizations cooperate to fulfil the conditions above. This cooperation has two necessary sides:

1. Integration of organizations with different scientific disciplines (integration of disciplines)
2. Collaboration of organizations with different roles of the three types (collaboration of roles)

These two are depicted in Figure 32.

In Figure 33, each block at the bottom is a panoramic view of research subjects which are based on common scientific discipline or role. When organising a full research, one research subject is selected from each panoramic view and combined in the upper block of the figure.

The upper block is a full research which has a two dimensional structure: integration of disciplines and collaboration of roles. This seems like a small indigenous knowledge and will achieve a research goal or result which explicitly contains a function recognisable by society. If it explicitly contains the function for society, it may well be said that in most cases the possibility is high for it to be connected to the social wishes expressed in functions, increasing the conformity between wish and science. When thinking a practical research programme, the full research will be constructed by networking some researchers or research spots. The network, the research result of which has a function recognisable in society, is called functional network of research, and when it loses the function by any separation, we call it a minimum functional network, which has significance in the discussion about issue oriented innovation.

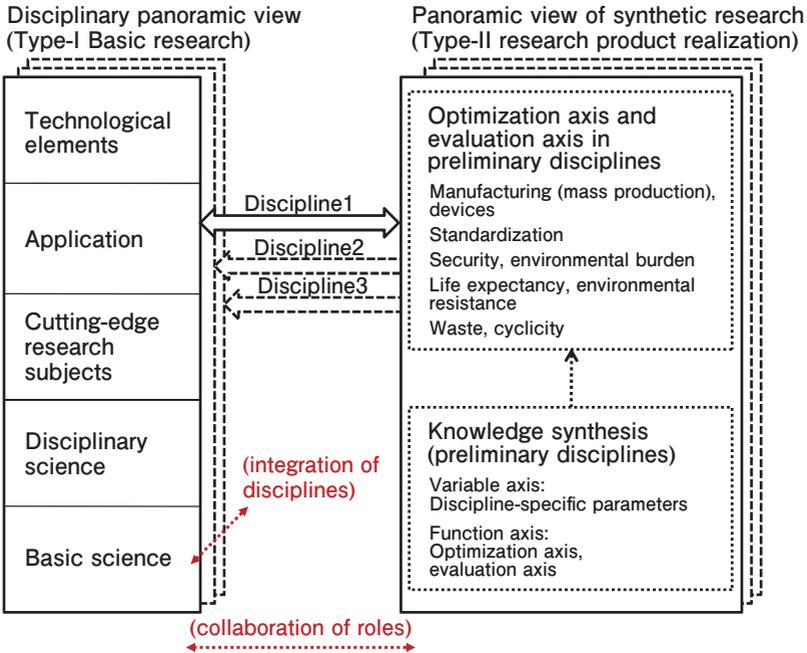


Figure 32 Encounter by integration of disciplines and collaboration of roles : Mapping between social wish and science

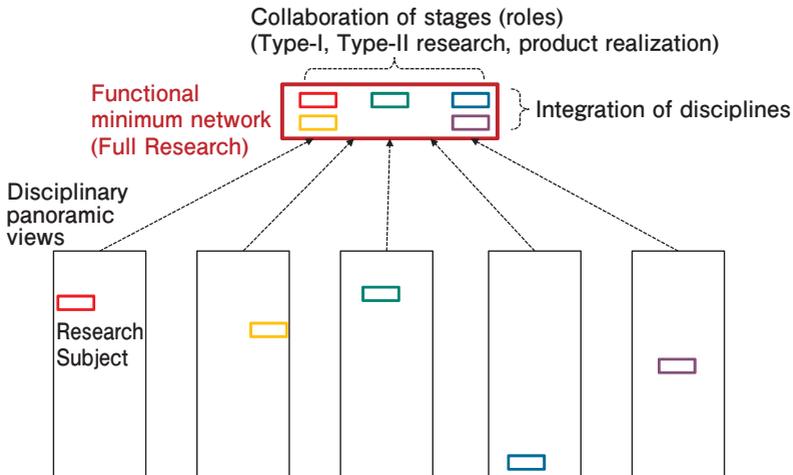


Figure 33 Extracting functional minimum networks from groups of disciplinary panoramic views

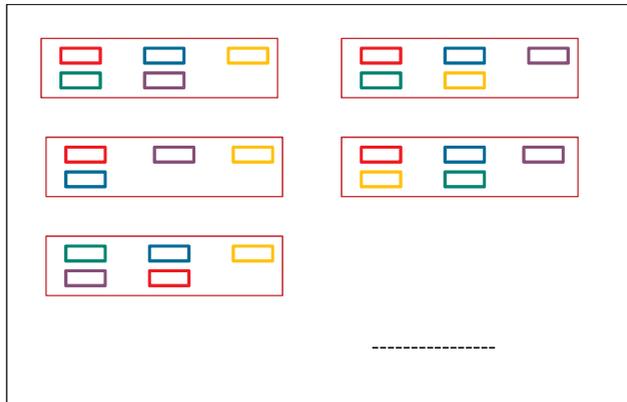


Figure 34 Full Research panoramic view

By establishing a full research or functional minimum network by certain rules, it should be possible to obtain a "panoramic view of full researches", like in Figure 34, instead of a panoramic view of research subject. If this panoramic view can be drawn on the plane with the same axis as the panoramic view of social wishes as shown in Figure 19 in Chapter 4 (Elaboration of social wishes), social wishes and research programmes (full research) "conform" with each other. The scale of horizontal axis of social wishes shown in Figure 21 is reach of action which designates the expansion covered by the wish. The scale of vertical axis is the scale of action which designates the size of every action by an actor. In the case of full research, reach of action and scale of action can be shown, so panoramic views of wish and programme are drawn on the same plane. Therefore, the conforming relationship of both is obtained and it guarantees the realisation of "encounter" of social wishes and research programmes.

Figure 35 shows a simple example. Silicon carbide has ever attracted the interest of designing researchers because of its interesting physical properties which were discovered by observing researchers long time ago, and there are many reports which showed the possibility of practical application as a semiconductor for high temperature use [16]. But it was not used practically for business purposes. However, it received recently

considerable attention as an important element for energy saving power systems and its implementation was planned. This implementation is not accomplished by further research on physical properties that spans back to the 1940s (i.e., Type-I basic research related to physical properties), and instead different researches were necessary such as precise control of crystal growth and precision processing of brittle materials. Control of crystal growth and precision processing are designing research, but both are based respectively on crystal growth theory and brittle fracture theory (which are Type-I basic research) different from the physical properties of silicon carbide. Thus, for implementation, the results of those basic designing researches were necessary, which means two types of synthesis—integration of different disciplines and role collaboration between observation and design—are necessary.

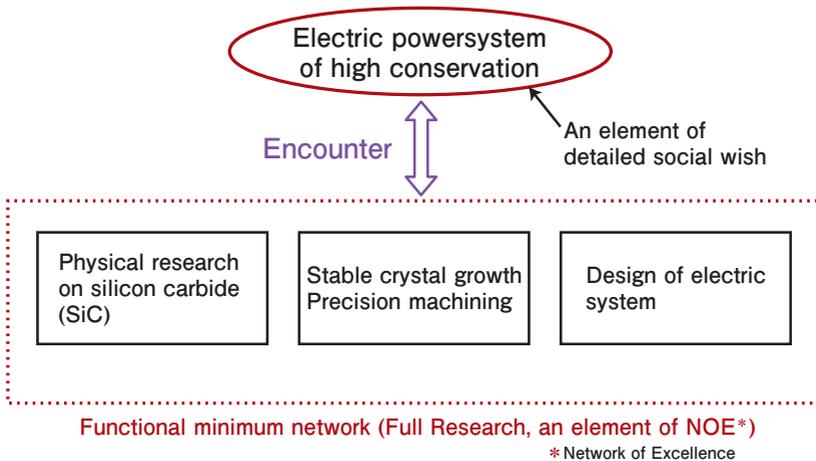


Figure 35 Encounter of Detailed Social Wish and Full Research

Moreover, to actually use silicon carbide as a power transistor, a drastic change in power system design is necessary, so research using the systems engineering, and finally the results of research must be utilized by an electric power enterprise as a social actor. It seems not enough to simply leave this process to spontaneous market mechanism in order to avoid falling behind the ever more rapid changes in the global environment.

Some policy for their integration should be introduced to accelerate the process. It is also necessary to create a research funding system that makes all this possible. This will be discussed in Chapter 6 (Research Fund Distribution). Using the examination above as a prerequisite, we here introduce the "structured panoramic view".

The discord in the scientific cooperation shown in Figure 18, that is the obstructive factor in the cycle, is solved by introducing the full research approach. Full research enables the collaboration of observing research, designing research and product realization. It implies basically a revolution of the thought process of scientists, but practically can be almost entirely implemented by forming relevant research organizations, with adequate management of research activity.

Let us remember how the observation of society and nature in the cycle was obstructed by insufficiencies in both situation observation and holistic observation by scientists. And it corresponds exactly to the promoting process of encounter to understand and eliminate the obstruction from the loop.

The discovery of invisible social wishes (the third level) necessary for the encounter requires holistic observation of change which is quite new for observing researchers who have observed individual changes in nature and society. Wishes obtained as the result of this research are beneficial to the acceleration of the cycle. The reason is, in contrast to diversified visible wishes where the basis is not always clear, that the discovery of invisible social wishes is something gained by the process of surveying the whole by using many scientific disciplines, showing the relationship between the wishes and then identifying them with as logical a procedure as possible. Therefore, the contents are clarified analytically.

The cyclic loop is actually completed by full research and the encounter. And consequently the possibility for necessary knowledge to circulate through the loop is born. The procedure takes the following steps: First, a panoramic view of social wishes is depicted by invisible social wishes

mainly and then visible wishes whose bases are clarified by using various scientific disciplines. Then, a panoramic view of full research is depicted. These two views are expected to have conformity. If, like in Figure 36, the encounter can be found looking at both panoramic views at the same time, the cyclic loop will be completed by combining these two panoramic views.

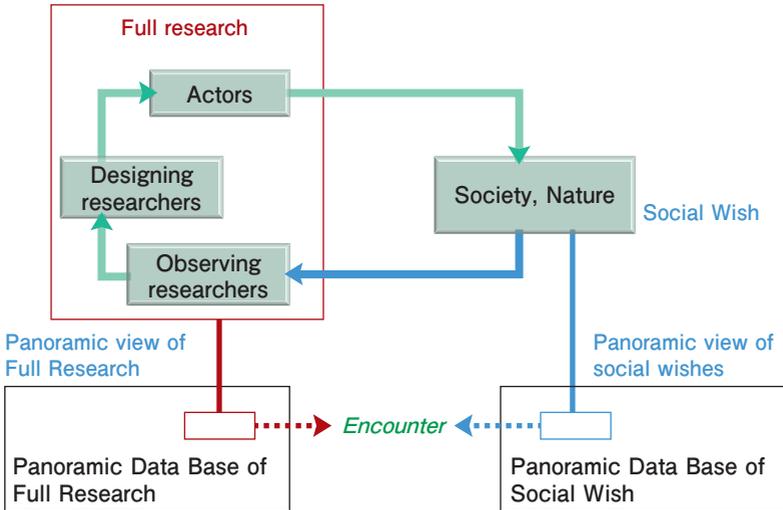


Figure 36 Acceleration by Encounter of Full Research and Social Wish

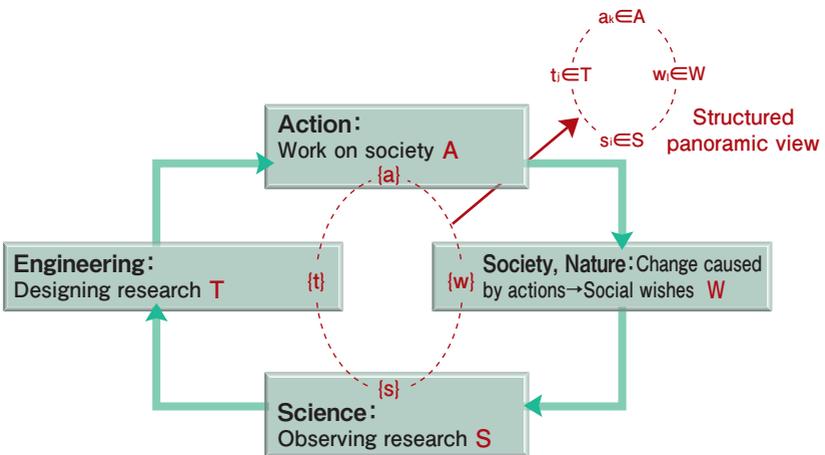


Figure 37 Structured panoramic view

Considering the above and by connecting four panoramic views of social wishes, observing science, and designing science and a list of actors as components, and then we obtain a loop in Figure 37. This loop is called a "structured panoramic view". This view corresponds to Figure 2 established as the basic relationship among research and society. Each component of Figure 37 can be seen as a panoramic view. By selecting conformable components relevant for a social wish, the loop in the top right of Figure 37 is extracted. It is then expected to become something having the basic framework of a strategic proposal for a research programme.

People of all nations will accept that the global warming became a serious global issue, and its suppression is now a common social wish in the world. Extensive research to stop the warming has already started in various fields. Here we shall consider the growth of this common understanding by using the structured panoramic view. Figure 38 shows the cyclic loop corresponding to Chapter 1 Figure 2 for the sustainable evolution that has been given a basic framework here, but each block is filled with all events occurred by turns. Each block in Figure 38 includes leading persons, engaged organizations and the subjects of research, international pacts or actions simply and without identifying the events with names of researchers, committees or involved organizations. The blocks are the panoramic views of the observing research S, the designing research T, the actors A and the social wishes W. Elements in blocks are written in the sequence of time, therefore by connection of elements through blocks will show a winding spiral of time series of events. Actually, the growth of the common understanding of global warming is the result of several turns of this spiral.

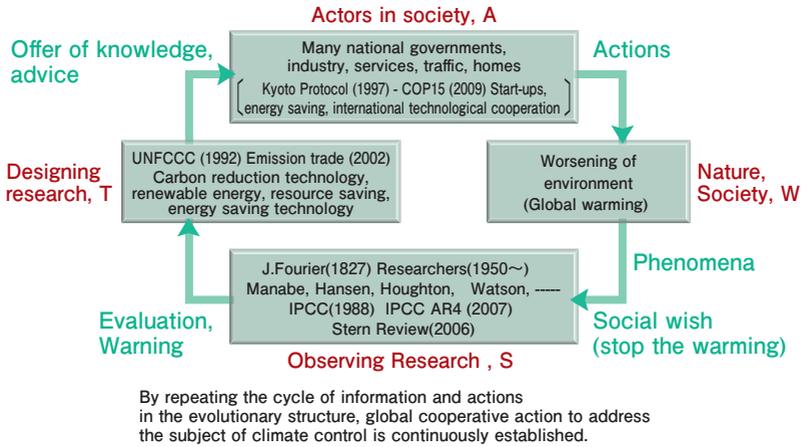


Figure 38 Structured panoramic view of the climate change

This loop shows only partially selected things from a bigger panoramic view of the social wish concerning the suppression of global warming, but we exactly understand that there was a panoramic view in the background from this simplified diagram.

This figure explains the following. Fourier coined the word "warming" in the 19th century, but this was of course not linked to sustainability. In the 1950s, the researchers Manabe, Hansen, Houghton, Watson and others started to warn about warming, but it did not really reach general society. However, with the joint international conference of scientists and administrators in Villach in 1985 it reached the UN, which adopted the United Nations Framework Convention on Climate Change (UNFCCC) treaty. Later, at the Conference of Parties, protocols influencing the actions of all nations were decided on, but after Kyoto a final global principle of conduct is still under examination. Meanwhile, emission trade was proposed and the seriousness of the problem was more widely recognized after the Stern Review.

Manabe and others are observing scientists, and in this process especially the warning of the IPCC had a great effect. It took 20 long years, but the

corresponding proposals by the UNFCCC and national governments are of the designing type. In fact, responding research on renewable energy and energy saving was conducted by designing scientists. The emission trade during that time can be seen as an important attempt to put the scientific warning into action. Stern has given it a scientific foundation.

If we look at the process of global warming this way, it can be seen that much knowledge was discovered and used, and actions affecting reality have started. This understanding comes from looking at the results, but knowledge selected from the overhead views of observing and designing science as well as actors was combined and connected to the social wish. In other words, the encounter has happened. More than 50 years have passed since the 1960s' warning to the present. It is too long and therefore shortening such a time period by using the structured overhead view is an important social wish and scientific-technological innovation is urgently requested to occur to satisfy the social wish.

It is a slightly different topic, but we will next discuss the Global Innovation Ecosystem (GIES), which is already an important idea at CRDS. It is illustrated in Figure 39 which shows an environment necessary for causing innovation efficiently. Of course, new knowledge related to science and technology as the starting point of innovation must be created, but also wider social conditions and the market conditions must be considered. Moreover, it is important to understand that the effects have on the innovation in mind such as related laws and systems as well as the ease of funds acquisition and human talent etc. In other words, all of these and a good condition of the whole environment surrounding innovation are necessary conditions for the success. These conditions are called the innovation ecosystem, as a metaphor for the eco-system as the environment of living things. Especially in the environment of our country, innovation is difficult to achieve, and in the present where a solution for this is urgent, such a concept for a solution is effective. It goes without saying that the items pointed out above must be examined.

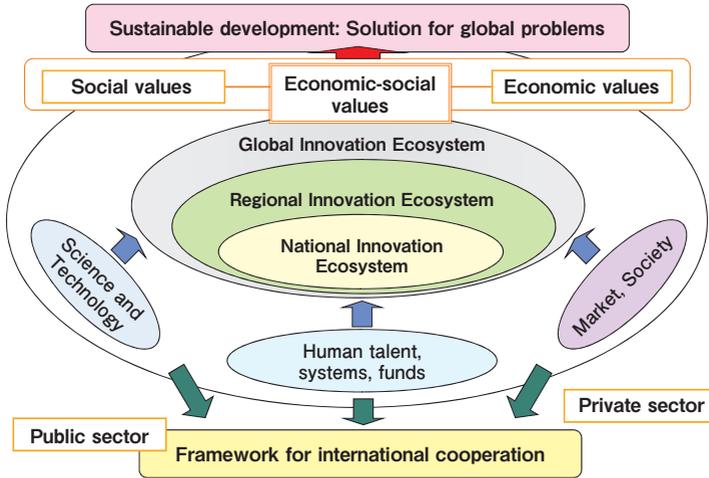


Figure 39 GIES: Global Innovation Ecosystem

Figure 39 neither shows a method for obtaining detailed information about all the components nor the direction of flow of information or the carrier of the components, so the structure behind the concrete action is not visible. However, the meaning of GIES is expected to become clear through refining the various sides of the system as structured panoramic views. Figure 39 showing GIES can be thought of as a platform for writing down the structured panoramic views. This will be examined sometime else.

## 6.1 Abandoning the linear model system

Japan's funding system for scientific research can be called a system that assumes a linear model of research where research sectors in charge of curiosity-driven basic research, target-oriented basic research, and product-realization research for industrialization are connected linearly in turn. These three research sectors are asked to perform their social responsibilities independently. Simply saying, it is assumed that there is a linear flow of knowledge from the upstream to the downstream of the linear chain of research sectors. On the contrary, the strategy for research and development proposed here aims at networking these research sectors so as to collaborate together playing particular roles in scientific-technological research to create values in society. The strategy is to organise networks of various research by the integration of disciplines and collaboration of roles so that sectors may exert their potential power as much as possible to create the largest results answering given social wishes. The evolutionary development of science and technology is assured only by construction of network of research sectors in which cyclic loops of knowledge are embedded. Now, we must abandon the linear model system.

If basic research for society means that researchers carry out research responding to social wishes, then the fund distribution systems of funding agencies may have the most important role to improve the relational conformity between social wishes and scientific-technological research activity. This can be understood from the fact that research funds for basic research are, as mentioned in the introduction, a public expense contributed by the people. In this case, elaborated social wishes must affect the implementation of research programme. Researchers, on the other hand, hold beliefs about what research should be done to fulfil the social wishes. There are usually dialogues between them about the design of research programme to improve the possibility to realise the social wishes. The distribution of research fund is decided by funding agency after this dialogue.

In order to maintain a high likelihood of the accomplishment of the research plan to satisfy the social wish, selection of proper researchers is

of highest requisite.

When funding agency selects a researcher or research group for a programme, it evaluates the accord of the research area of the researcher, their research achievements so far and potential research ability. In the case of basic research for society, these are fundamental and are not changed regardless of the distribution system. We thus do not investigate this kind of decision-making method. Instead we pay attention to how the research fund distribution system considerably influences the structure of the researcher's community, and look into what kind of distribution method would produce a desirable structure. Such a desirable structure aims at promoting not only individual research, but also innovation which is realised through the complex participation of a variety of researchers as mentioned in the last chapter. Thus, funding must try to encourage researchers to organise a desirable structure promoting such participation.

The current public research fund system for science and technology research in Japan is outlined in Figure 40. There are funding agencies having different missions: the Japan Society for the Promotion of Science (JSPS) is in charge of curiosity-driven basic research, the Japan Science and Technology Agency (JST) is in charge of target-oriented basic research, and other agencies attached to ministries such as the New Energy and Industrial Technology Development Organization (NEDO) which is responsible for development of industry supplies funds for product realisation. These agencies are connected following the linear model of research development as seen in the Figure.

These systems above mentioned have a long history in Japan and have contributed well for improving the level of research in Japan. Nevertheless, today our country has changed from one that is catching up with other advanced nations to one that is an advanced nation which leads in science and technology research. We must recognize, therefore, the need for change in individual research as well as change in the structure of researcher's community in Japan for increasing contributions to society.

First, it is necessary to revise the linear model. In the case of a country catching up, the promotion of basic research was most important in overtaking advanced nations. Because it worked well to follow the preceding examples of advanced nations in regard to the product realisation research at the heart of industrial application, our country improved the international competitiveness of manufacturing industries. However, as it is often said, most successful product realisation research in Japan was done by further improvement of already accomplished target-oriented basic research or the already socially realized technologies in advanced nations. We must say that there was almost no successful case achieved from the basic research to realisation in the linear model.

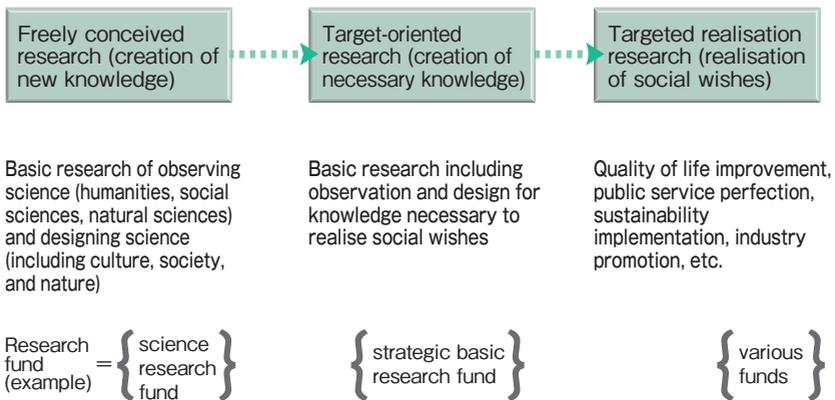


Figure 40 Research fund systems based on the linear model of science and technology

In this sense, the limits of the linear model talked about in Europe and the US were also discussed in our country, but the discussion in our country was never more than one theoretical. There are not many examples of success, including products competitive in the international market, that Japan realised commercial products based on curiosity-driven basic research conducted domestically. As a consequence, there is not enough experience of contributions to society based on basic research. Therefore,

before discussing the limits of the linear model, we must recognise that it is not widely understood in Japan what should be remedied in the research system in society.

At present, the level of basic research in our country has become high as a result of the Basic Law on Science and Technology and the Basic Program for Science and Technology based on the law. On this basis, there is now a sufficiently high possibility for satisfying social wishes including the promotion of industry using our own resources. However, there are still some problems. Some Japanese basic researchers have expressed concerns that overseas companies have greater interest in basic research in Japan that potentially promises implementation than do Japanese companies. They have also pointed out that the application of basic knowledge stops at the development of components, and successful cases of system products directly contributing to our country's economy are few. In the context at hand, this exposes the immaturity in Japan related to satisfying social wishes based on basic research.

How can we outgrow this immaturity? We can no longer learn from other countries. Certainly, the advanced nations in Europe and the US as well as emerging industrial nations are calling for an age of sustainability and are independently trying to develop new methods and looking for social contributions from science different from those of the past. Under such circumstances, researchers in these nations are making great efforts, under the political and social consent. Depending on the characteristics of its historical background, each of these countries has already begun to make efforts to devise a research fund system to address the social contributions from science.

Which path should our country take in this situation? This is nothing other than the research strategy discussion already mentioned in previous chapters. The things that must be pointed out here are the necessary requirements for research in the age of sustainability and, at the same time, the necessary requirements for our country to outgrow

our immaturity mentioned above. As is clear from the research strategy discussion in the previous section, the path ahead means we must actively abandon the linear model.

The research fund system examined in this section must, therefore, facilitate the movement along this path; in other words, it must support the progress of researchers on this path.

## 6.2 Alleviating dissolution of the research community

In the research and development strategy presented in this text, the integration of disciplines and the collaboration of roles are indispensable requirements. Our country's research fund system must not isolate researchers but must encourage researchers to build networks among them from different areas and different roles.

As mentioned in previous sections, one important point to ensure the research fund distribution system is that the system must endorse the researchers' recognition of their roles as well as their cooperation with other researchers who have compatible roles. As stated above, integration of disciplines and collaboration of roles are necessary to make the implementation of the functional minimal network possible, but this requires cooperation across disciplines and organizations. For this purpose, we next discuss the need for careful consideration when putting into place a competitive research fund system.

When one visible social wish is given as a research target, there should be diversified researchers normally who are ready to apply different methods towards the goal within the same disciplines or different disciplines. In regenerative medicine for example, the kinds of animals, treatment methods, and other things used as research means must be wide-ranging. In the case of information transmission with low energy loss, researchers are using varied transmission principles and materials. Suppose there is a research funding system with a large research fund under an extremely high competition rate (e.g. one person out of one hundred in a discipline). If one researcher who proposed the most promising research method is chosen as the candidate, other researchers working on the same goal lose the possibility of obtaining research fund in the meantime.

A competitive research fund cannot avoid this situation, but researchers who could not receive fund will not be able to obtain another research fund for the same research subject anymore and so will be forced to change their research topic. In this case, a group of cooperative researchers who

have shared the same goal will be broken or dissolved and consequently they move to a different disciplines and this research cooperation ends. It might also be possibly worse that they try to avoid doing similar research to other researchers from the start, rather than cooperate.

We refer to this as segmentation of research community caused by competitive research funds. Some may try to avoid cooperation from the beginning to maintain originality, but it is wrong. When illustrated, this produces something similar to Figure 41. This figure shows the possibility of successive dissolution of friendly group happening as a result of such research funds: this way, the network necessary for the innovation discussed in previous sections cannot grow. Moreover, there is the possibility that research funds break existing networks. This is, of course, problematic.

In order to not only prevent this, but also develop encourage researchers to organise networks, it is effective to implement a funding system that provides research funds to networks. Figure 42 compares the traditional centre of excellence system with the network of excellence system. The former is effective in creating a single strong school and will be useful even in future. However, if the aim is not to grow an academic school within a discipline but to accomplish an innovation which directly contributes to society, a research fund distribution is indispensable which requires at least the creation of minimum functional networks as network elements. As discussed in the structured overhead view in Chapter 5, minimum functional networks are connected with different disciplines and researchers holding different roles, who in turn may belong to different departments or different universities and research organizations. Therefore, we need a research fund system that targets researchers who are linked to form functional networks, at least minimum functional networks.

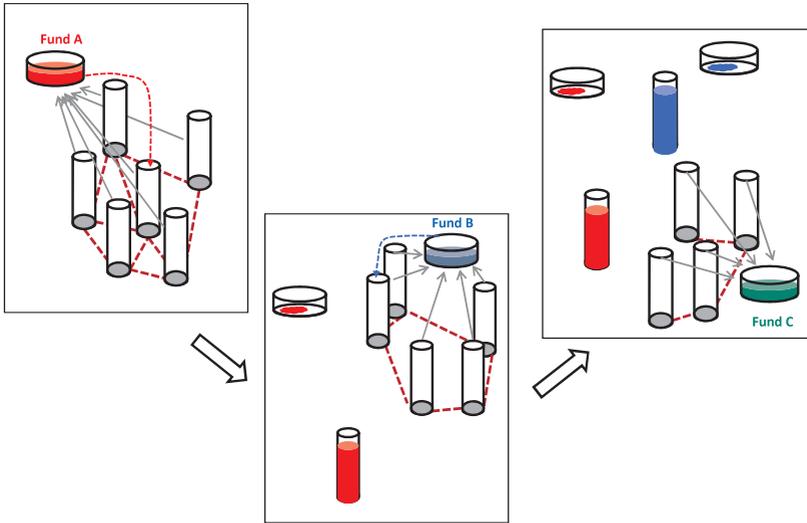


Figure 41 Dissolution of research community due to excessively competitive research funds

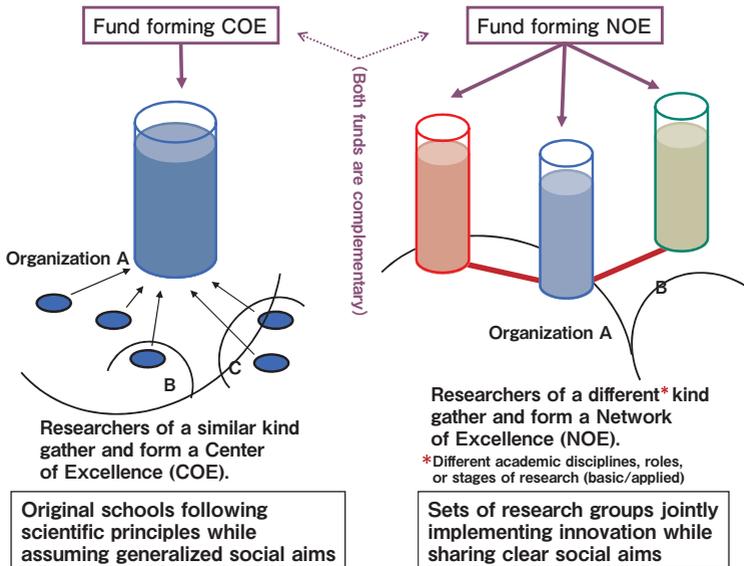


Figure 42 Research fund supporting networks

## References

- [1] Vision, Mission – CRDS (About us), <http://crds.jst.go.jp/about/mission.html>
- [2] D. Meadows et al. : *The Limits to Growth*, A Report for THE CLUB OF ROME's Project on the Predicament of Mankind, 1972.
- [3] H. Brundtland : *Our Common Future*, The World Commission on Environment and Development, Oxford University Press, 1987.
- [4] J. Lubchenco : *Entering the Century of the Environment : A New Social Contract for Science*, Science, Vol.279, 491- 497, 1998.
- [5] *The New Growth Strategy (Basic Policies) (December 30, 2009 Japan Cabinet Decision)*, 2009.
- [6] H. Yoshikawa : *Full research*, University of Tokyo Press, 2009, pp. 97-110. (Chapter 2, "Necessary conditions of full research", Chapter 3 "Innovation through full research")
- [7] J.W. Forrester : *Industrial Dynamics*, Cambridge, Mass., MIT Press, 1961.
- [8] R. Lester, M. Piore : *Innovation - The Missing Dimension*, Harvard University Press, 2004.
- [9] H. Yoshikawa : *View of Artefact*, Journal of Transdisciplinary Federation of Science and Technology, 1 (2), pp. 59-65, 2007.
- [10] C.S. Peirce : *Collected Papers of Charles Sanders Peirce*, vol.1, Charles Hartshorne, Paul Weiss (eds), Thoemmes Press, 1931.
- [11] *Synthesiology*, Quarterly Journal for research on synthesis, National Institute of Advanced Industrial Science and Technology (AIST), 2008
- [12] H. Yoshikawa : *The New Role of Scientists*, Chapter 3, Iwanami Shoten, 2002.
- [13] R. Merton : *Social Theory and Social Structure*, The Free Press, 1949, 1957.
- [14] K.R. Popper : *The Poverty of Historicism*, Routledge and Kegan Paul, 1957.
- [15] H. Yoshikawa : *Introduction to General Design Theory*, Journal of the Japan Society of Precision Engineering, vol.45, no.8, 20-26, 1979., also see *General Design Theory and a CAD System*, Man-Machine Communication in CAD/CAM, T.Sata, E.Warman (eds.) IFIP 1981
- [16] J.R.O' Connor, J. Smiltens (eds), *Silicon Carbide*, Pergamon Press, 1960.

# **Design Methodology for Research and Development Strategy**

— **Realising a Sustainable Society** —

Japanese edition published in June 2010  
English edition published in February 2012

**Hiroyuki Yoshikawa**

CRDS-FY2011-XR-01

---

Center for Research and Development Strategy  
Japan Science and Technology Agency

<http://crds.jst.go.jp/>  
@2012 JST/CRDS

---

No part of this publication may be reproduced, copied, transmitted or translated without written permission. Application should be sent to [crds@jst.go.jp](mailto:crds@jst.go.jp). Any quotations must be appropriately acknowledged.

# Design Methodology for Research and Development Strategy

Realizing a Sustainable Society —————

Center for Research and Development Strategy  
Japan Science and Technology Agency