Synthesiology: Knowledge for interdisciplinary consilience

[Translation from *Synthesiology*, Vol.3, No.2, p.158-163 (2010)]

The 3rd Conference organized by the Transdisciplinary Federation of Science and Technology (TFST) was held at the Tohoku University in December 2009. The special session entitled "Synthesiology: Knowledge for Interdisciplinary Consilience" included a lecture and a general discussion. The outlines of the general discussion and the paper read of the lecture are presented here with the permission of TFST.

***Synthesiology* Editorial Board**

[Opening address]

Hisatoshi Suzuki (Vice-Chairman, TFST; University of Tsukuba)

The Transdisciplinary Federation of Science and Technology (TFST) is an organization that was formed for the development and promotion of core sciences, which are the foundation of technology, different from natural sciences. It is a federation of the academic associations of various specialties, across humanities and sciences. In January 2008, an academic journal *Synthesiology* was launched by AIST. I think the objectives of the journal, "to establish a discipline to synthesize things that are beneficial to society by integrating the scientific findings and technologies in addition to the traditional science for obtaining the knowledge on nature", as well as the methodologies presented in the papers published in the journal share close semblance to the thinking of TFST.

A joint workshop was held by TFST, the Institute of Statistical Mathematics (ISM), and AIST with the objective of promoting this field in January 2009. This effort was extremely significant, and led to this special session of the 3rd TFST Conference.

Dr. Akira Ono, the Vice-President of AIST, will lecture on the essence of the AIST method of synthetic research to "utilize the results of the basic research in society". Then we shall have a general discussion with Dr. Motoyuki Akamatsu as the coordinator.

[Lecture]

Akira Ono (Editor in Chief, *Synthesiology*; AIST)

[Refer to the paper, "Synthesiology: The method and description of synthetic researches" on pages 179~183 in this issue.]

[General discussion]

Motoyuki Akamatsu (Executive Editor, *Synthesiology*; AIST)

I believe one of the aims of TFST is "integration of knowledge", and the synthetic research addressed in *Synthesiology* is "integration" in many ways, and I think we are aiming for common grounds. Therefore, in this general discussion, we shall have a three-way discussion with TFST, AIST, and ISM which is a supporter of TFST.

Synthesiology publishes papers of varying fields. To avoid the discussion from becoming too abstract, we will have Dr. Atsuo Kishimoto of AIST explain his paper "Strategic approach for comparing different types of health risks" that was published in Volume 1 Issue 1, as a specific example of synthetic research.

Next, we shall hear from Dr. Tatsuji Hara on which direction the synthetic research should go from the standpoint of TFST, and then from Dr. Yoshiyasu Tamura from the standpoint of ISM. Dr. Naoto Kobayashi will explain the types of "synthesiology" scenarios. Finally, we shall engage in discussion.

[Strategic approach for comparing different types of health risks]

Atsuo Kishimoto (AIST)

Rather than getting into the content, I shall focus on the "way of thinking" presented in this paper. While I am not certain whether my research represents a typical AIST style, because I was given an opportunity to write for *Synthesiology*, during the writing process, I think I was able to organize my way of thinking at the time I was doing research, and I caught myself saying, "Oh, so that's what I was thinking!"

My research is risk assessment of chemical substances. I had to think of a way to rank the risk reduction measures in Japan according to priority for about 100 thousand industrial chemical substances. To do so, I had to compare the magnitude of the risks of various chemical substances.

Risk can be expressed by multiplying the level of exposure and the strength of toxicity. Combining the two data for the distribution of exposure level for all Japanese, and how much increase there is in the incidence rate when the exposure level increases, and then looking at the size of risk of each chemical substance, these become the "necessary information". However, it was found that the "available information" amongst the "necessary information" were way insufficient.

For exposure level, there are several examples of people exposed to extremely high concentrations. For example, there are many examples of extremely high measurements of formaldehyde concentration in a newly built house and short-term daily average values. However, there was hardly any data on long-term annual average values that we wanted to obtain, nor was there data showing the seasonal changes. For toxicity, there were data for no-observed-adverse-effect level of "concentration below which no adverse effect will occur", but there was no data for dose response function showing "this much incidence rate will occur if there is this much exposure". Therefore, the current elemental technologies could not be used, and we had to on our own develop and modify the elemental technology.

The "existing elemental technologies" that we determined to be "useless", while they include the ones I recognized after I wrote the paper, were the ones for the risk assessment of chemical substances reflecting the initial demands in society. These elemental technologies were selected when conducting a chemical substance screening, which involved the elimination of no-risk substances amongst the milliard chemical substances. Therefore, the method to achieve that objective was pursued. The elemental technology was developed to find the level that was safe for high concentration exposure, and it was optimized for the work of saying "if this substance is okay at high concentration, then it is safe at ordinary concentration".

The elemental technology thus developed was established by repeated practice. Guidelines and manuals were written, became routine, and the methodology for the initial risk assessment for chemical substances was established.

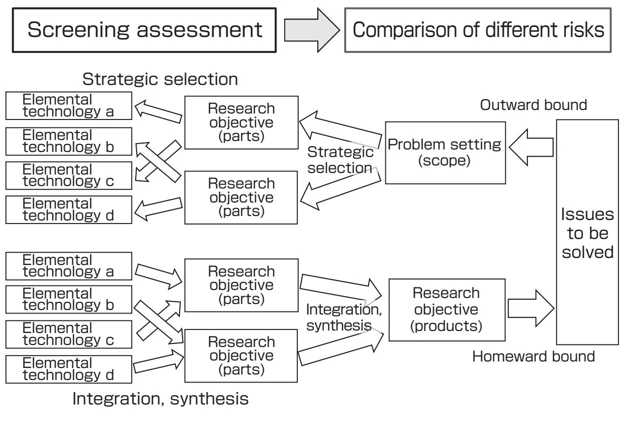
However, what we were trying to do was "risk comparison for several types of chemical substances", and in a sense, it was a new social demand. The existing elemental technology was inappropriate for this purpose. The existing elemental technology was for a different social demand, because it was a part of the set of elemental technologies optimized for screening assessment. Therefore, we became aware of the gap where we could not use the risk assessment technology for the new demand.

We returned to the origin, and started looking at the methodology of which elemental technology was necessary to enable the "comparison of different types of risks" that was the new social demand. This is called "re-synthesis" in "synthesiology". Rather than measuring only the people with high exposure concentration, we looked at the distribution of annual average values of the individual exposure estimate and the distribution of the environmental concentration estimates in Japan. Rather than looking at one value where anything below it is safe, we looked at the whole picture, and saw that there were various elemental technologies that must be optimized. Development of these elemental technologies is the "strategic development of elemental technologies". Next, the elemental technologies developed are integrated and synthesized. Then, we enter the phase of "integration and synthesis of various elemental technologies" where we establish the new methodology and put them in practice.

The essence of the paper written for *Synthesiology* was to develop a new methodology and to conduct risk assessment to compare the various types of risks.

When I was doing this, I thought about "the trap of the fields of specialty". It may be extravagant, but the currently existing specialty and research topics were always derived from some past social demands. The "fields of specialties" that were formed became divorced from their origins and went through their unique evolution. For example, they generated academic societies, specialists, guidelines, journals, courses, and textbooks, and became autonomous. However, social demands and societal values are ever changing. In modern society where changes occur dramatically, the specialties fall into autotelism, and I

Changes in issues to be solved by risk assessment of chemical substances



painfully realized that they might have become so distant from social demands. Of course, it isn't that the existing elemental technology is useless. It is useful for screening chemical substances, but it is not directly useful for any other purposes.

I think there are outward and homeward passages to solve an issue. In "synthesiology", the main passage is homeward bound from integration and synthesis to the goal (product). To do so, there is a strategic selection of reviewing all elemental technologies, and I think I walked outward when I thought about how to combine the established technologies. When the social issue that one wishes to solve changes, this cyclic path is traveled again, and when another issue that must be solved arises, you must walk through the cycle yet again.

[New academic system]

Tatsuji Hara (The University of Tokyo)

I was the chief editor of the journal called the *Okan* or the Journal of TFST for two years, and currently, I am a senior member of the Knowledge Integration Subcommittee, Integrated Engineering Committee, Science Council of Japan, under Chairman Tachi. I would like to present my thoughts, along with the activities of TFST.

When Dr. Yoshikawa was the chairman at the Science Council of Japan, the framework of science for recognition and science for design were created for the "new academic system". While conventional "science" corresponds to science for recognition, it is academics for science, and is the "pursuit of what is" On the other hand, science for design is what is conventionally called "technology", and this is academics for society, and is "the pursuit of what should be". Both academics based on intellectual curiosity and academics focusing on values and objectives are equally important, and this is the new system of academics.

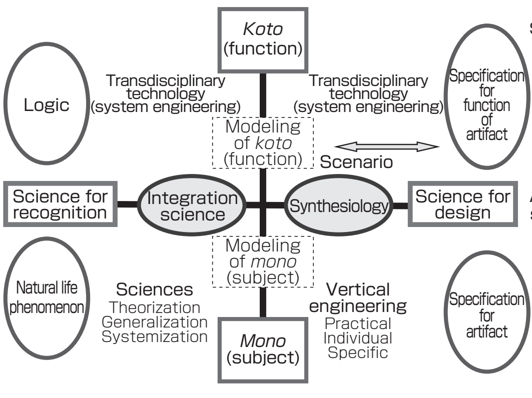
I considered along the two axes: one of science for recognition and science for design, and the other of *mono* and *koto* proposed by TFST.

What we called science for recognition and science for design at the Science Council might correspond to the way of thinking focusing on *mono* (subject). Science for recognition is roughly considered "science" where the subject is nature, life, and phenomenon, and aims at theorization, generalization, and systematization. In contrast, science for design is an artifact system, or designing and realizing the artifact. It is characterized by keywords of practical, individual, and specific. I think it corresponds to the conventional vertical engineering based on the vertical disciplines such as mechanics and electrics. These more or less look only at the *mono*. However, to actually create an artifact system that is useful to society, both *mono* (subject) and *koto* (function) are necessary. Science and vertical engineering are firmly established as disciplines for accurately understanding the "subject". However, for system engineering and system theory that are transdisciplinary technologies to be valid, it is necessary to define what corresponds to the specification of the "function" for "subject".

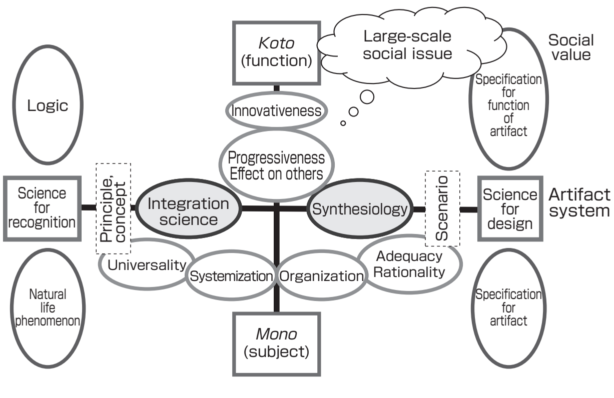
When we think "what is 'synthesiology'", it is not just "subject" and it is not just "function", but it probably aims right in between. As a contraposition to "synthesiology", I shall set "integration science" since the other keyword of TFST is "knowledge integration". If this integration science and "synthesiology" correspond to the new science for recognition and science for design that deal with "subject" and "function", I think that is one way of drawing the picture.

I think "scenario" will be the major keyword for "synthesiology", which is a "scenario-driven research". When we look at the "subject", to conduct an academic study, one standard way of science and technology is to create a model for the subject, and then conduct research based on this model. However, I don't think "modeling of function" has been sufficiently done. Therefore, when we say "subject" and "function" are two wheels of a vehicle, it is necessary to define function modeling. Considering these and then thinking what a scenario is, I think the scenario is to connect the model and the specification for the function of artifacts. It is to consistently and rationally link these two.

"Transdisciplinary science and technology" + "synthesiology"



Evaluation in "integration science" and "synthesiology"



For evaluation, what should be assessed in “synthesiology” and integration science? The integration science is to create new principles and concepts for integration, to pursue universality based on those principles, and to systematize. In “synthesiology”, consistency and rationality are important. Consistency is to bind the separate items into one, and it is also to establish a single scenario, and these are different from the logical consistency. Perhaps “rationality” should be called “adequacy”. In Dr. Kishimoto’s example, the methodology can be used in other places, not only for solving the risk comparison. It will become universal by systematization and generalization. When it is possible to define “consistency in this sense” as a new evaluation standard, I think evaluation is possible. Whichever it is, it will be based on a scenario.

Another point is, since our subjects are large-scale, complex social issues, we must question “whether it is innovative, or progressive, and whether there are effects on others” in our evaluation. To prevent systematization and universalization from anchoring the subject in that field, it is important to accurately evaluate the progressiveness and effect on others.

The transformative research, for which support is considered by NSF, is an attempt to transform science through revolutionary developments. In the United States, unexpected developments, effect on multiple fields, and creation of new research disciplines are expected. The European-type fusion is where a team is created to conduct the fusion research to arrive at an innovation, and is an attempt to gain something through fusion.

In Japan, the fusion research is not necessarily going well. The reason is because, when an area of concentration is determined, the research activities go straight to the center, the objective will be solving the problem and whether one gets a result or not. It is even doubtful whether the fusion research is really being conducted.

In such situations, I think I would like to see a proper academic approach to the social issues through “synthesiology” and integration science, and that may produce progress and effect on others.

[ISM and synthetic research]

Yoshiyasu Tamura (ISM)

Because of the term “statistical data analysis”, many people may think statistics is analysis, but it is in fact the opposite, and I feel there are many “synthesiological” factors. In the past, a research on cement was conducted by Dr. Akaike at ISM. To operate the cement kiln stably, no conventional method worked, so a new statistical control method was considered, and this turned out to be successful.

I’ll talk about studies done by graduate students. The first research by a student who got his doctorate in March was a study on “where the respiratory center was located in the rat brain”. He really loved mathematics and wrote all these mathematical models, and was scolded by the physician. Why was he scolded? Because he neglected physiology. The physician pointed out, “That kind of research is no good”, but the graduate student was so shocked he quit the research. Another graduate student had been working at a control system company, and was a very experienced 60 years old. His data was dyed slices of the brain that he looked through a microscope, but he grasped the heart of the research. While using mathematical techniques and statistics, he was able to match the physiology and the model because he had hands-on experience in problem solving and did not get entangled in virtual mathematics. The student who failed with the rat brain went on to analyze the shape of the rat jawbone. The quantification of shape could not be done with existing techniques. So, he used the data from the Institute of Genetics, and now seems to be successful.

It is often said that “fusion research was never successful”, but the fusion research between the National Institute of Genetics (NIG) and ISM is going fairly well. That is because genetics and statistics share the same roots, and the geneticists and statisticians seem to get along very well.

At ISM, there are many students who come from the financing world, and their objective is “how to prevent the company from suffering losses”. They think about what scenarios to write and how to gain most profit by using quite difficult differential equations for probability. Various elemental technologies are combined. Since the scenario model for what to select to get the best is the most important point in statistics, I think statistics has always blended well with the “synthesiological” way of thinking. What we call analysis is the analyzing done at the final level, but “what kind of analysis should be done” must be carefully integrated and synthesized.

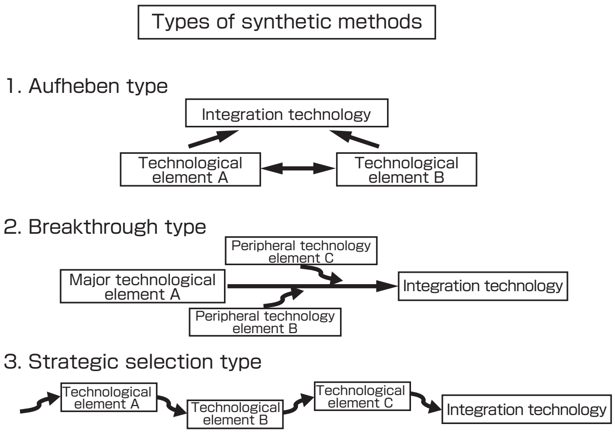
Right now, the people of statistics and information science like to use the word “data-driven”, and they say the fourth science is the “science of data”. Modeling of data may sound strange, but what is most important is how to model the system that generates the data, and I think it mixes well with synthetic research.

[Categorization of synthetic method]

Naoto Kobayashi (Waseda University)

Since my specialty is physics, I tend to think analytically even when talking about synthesis. Therefore, I shall look at the synthesis method in an analytical manner. This figure was presented when I had a discussion with Prof. Richard Lester of MIT in *Synthesiology* Volume

1 Issue 2. As I read the published papers and talked to the authors, I saw there were different synthesis methods in the papers, and I categorized them into three groups.



First is the “aufheben style” borrowed from the Hegelian dialectics. This is a type where different theses such as technology factor A and technology factor B are integrated, and some new concept is created.

Second is the “breakthrough type”. The scientists and engineers are fairly good at this. It is a type where one’s elemental technology generates a technology that will become a key, and when the peripheral elements are bound to that technology, an integrated technology is formed and then there is a breakthrough. Actually, things are not that simple, but there are some successful cases.

Third is the “strategic selection type”. Dr. Kishimoto mentioned outward and homeward passages, and when I read Dr. Kishimoto’s paper, I thought it might be this type. The exit is set first, and various elemental technologies are selected and synthesized to get there. In this case, the importance of the individual elemental technologies is similar, but a strategy is needed to select and synthesize them.

Of course, there are other types, and combinations of the three types. I also think it is rather difficult to have a clean-cut categorization. What is more important is the essential leading principle when synthesizing these elemental technologies.

We’ve been going around asking people to understand the objectives for launching *Synthesiology* and to write papers, but I don’t think we have arrived at a methodology of synthesis yet. When I do the reviews and explain the importance of scenario and synthesis of elemental technologies to the authors, I ask, “You mean this, right?” and they say, “Oh, you may be right. But I wasn’t thinking about that at all”. I think this part is similar to the argument by Dr. Hara that “‘synthesiology’ is a scenario-driven research, and the definition for function modeling is necessary”. It is perhaps very similar to the argument for innovation. Although the road may be long, perhaps we may be able to reach a methodology for the integration of knowledge.

[Question and Answer]

Akamatsu

Does any of you in the audience have questions or comments for the four speakers?

[Does the “artifact” include company?]

Audience

This may be a simplistic question, but is it okay to include something like a company among the artifacts? Dr. Kishimoto talked about risk. There is a way of thinking that avoiding risk will be beneficial to the citizens, and a company too faces several risks such as management issues and earthquakes. I have surveyed the standard for risk management, and the direction emphasized in the risk management standard by the companies based in Australia and New Zealand is “risk is chance”. Rather than avoiding risks, the companies can create innovations using the risk as a chance, and raise its new corporate value. As this method spreads to other companies and become commonplace, not only does the immediate corporate value increases, but the benefit is returned to the entire society. When investigated from the company’s standpoint, it isn’t entirely mathematical because the business models or somewhat incomprehensible elements enter, but can these be included in the artifacts?

Kishimoto

I spoke about citizens when I talked about the entire Japan, in the sense that we engage in researches as public institutions. We do consider “a risk is a chance”. To capture what may be the risk in the future, to develop a method, and then to standardize the method—this will lead to the competitiveness of Japan. To do so, it is necessary to specify “for whom”. If it is specified “for the company”, the strategy for companies will be created, and we can apply the “synthesiological” framework.

Hara

I wrote “artifact system” in the figure, and that was proposed at the Science Council. When we considered *koto* or subject, it includes the social systems and the human endeavors, and I think it should be taken as a very wide-ranging concept.

[Organization of knowledge integration]

Audience

When we talk about “knowledge integration” and “synthesis”, I think we should organize the different domains of the structure of “knowledge” that are considered as a subject.

First, there is the domain that can be investigated by the natural providence such as nature and the physical world. Next, there is the logical world or thinking world, and in this there may be mathematics and models. The problem is the type that deals with the so-called human society, and this includes intentions, meanings, values, and includes ourselves who are trying to do the investigation. Moreover society includes nature and engineering. I think the knowledge integration should be organized by three dimensions. The integration that links those three may be ambitious, or there may be a new type of movement called the ad hoc integration for some problem solving.

Akamatsu

When there was a discussion on why launch another journal when there are already millions of journals in this world, I thought unless we accumulate case studies, theorization alone will be unusable, and we must collect the data of successful cases of research and learn from them. Therefore, in *Synthesiology*, there are papers on various researches that the editors and the authors consider to have synthetic approaches. As presented by Dr. Kobayashi, we are trying to categorize research by trial-and-error, and I think the categorization suggested by the audience just now is also possible. Since we just started collecting case studies, I think we shouldn't hurry, and we can take time categorizing as more cases are accumulated.

Audience

Dr. Hara's figure ("Transdisciplinary science and technology" and "synthesiology") is very interesting, but I would like to ask one point. While the natural phenomenon is a subject, what is the positioning of the social phenomenon? Does it belong to a different world? Can the social phenomenon be expressed in this figure just like a natural phenomenon? Is society somewhere outside, and is the knowledge accumulated and the logic built here given some sort of meaning in a separate society?

In my thinking, it is assumed that "science is also a social phenomenon". Society is moving and science is moving. I think what is challenging and interesting is the interaction between the two, and if you express this in this context, you may appreciate the advantage of TFST.

Another point,—you use the word "synthesis" to mean the lump held together by multiple logics and how they will be made into one story. "Integration" is to become one through combinations in a deeper way. Until now, various fusions of different fields were attempted, but they are difficult. I think synthesis is more practical in reality. Ultimately, I think some kind of fusion will take place, a new discipline is born, and that will go into a cycle to become something new.

Akamatsu

What we target in *Synthesiology* is the "activities of the researchers". We suppose there is a social background that moved the researchers. Dr. Kishimoto's research is a research done through the interaction with society. You become aware when reading the papers of *Synthesiology* that there are several researches conducted with the background of the interaction among the researchers of a research organization or the interaction between the researcher and industry. Rather than targeting only the completed product, what is important is the process where the researcher interacts with society, defines the goal, and thinks what must be combined together to achieve the goal. One of the objectives of *Synthesiology* is to describe this process as papers, whereas such things were done before without much thought given to them. Therefore we chose not to use the word "integration", but decided to use the word "synthesis" to express the process of gradually building something.

Today, we were able to discuss many points, and I hope we will all continue to work hard. Thank you very much.

[Closing Address]

Hidenori Kimura (Chairman, TFST; Riken)

About two years ago, I heard about the launching of *Synthesiology*, and I honestly thought, "Wow, they got there before us". They were doing exactly what we were thinking, and the results are impressive too.

Dr. Yoshikawa stated that the discipline is necessary for the field to develop, and even said that it is a necessary evil. He believes that the passion of the researcher will always overcome the evil and solve the problem. Dr. Kishimoto who spoke today has first-handedly experienced the limit of the discipline, has overcome that, and yielded wonderful results. However, the academic societies are set up by disciplines, and if we call that necessary evil, we will end up with a contradiction that academic federations cannot exist. Therefore, we must strike a balance, acknowledge their existence, and seek the passion for overcoming them. I think this is the direction that must be taken for the academics to advance in the future.

AIST that harbors several thousand excellent researchers started this activity, and we would like to pay attention to their activities in the future. We would also like to provide as much support as possible as academicians.

Synthesiology: The method and description of synthetic researches

A. Ono and M. Akamatsu (National Institute of Advanced Industrial Science and Technology)

[Translation from *Synthesiology*, Vol.3, No.2, p.164-168 (2010)]

Abstract - A new method and processes are provided for synthetic researches integrating elemental technologies to realize societal values. The synthetic researches are characterized in comparison to the analytical researches and are modeled in the cycling processes among society, researchers and academic communities. A new description framework is given to writing original scientific papers of the synthetic researches. It is now demonstrated by the publication of a new scientific journal, *Synthesiology*, for the synthetic researches.

Index terms - Synthetic research, method, description, type two basic research, synthesiology

1 Introduction

The science has a great history that it advanced dramatically since the 17th century using the method of reductionism. It has been recognized, however, in the 21st century that this method alone will not be able to address the complex issues such as the global environments. In the 20th century, the technology has greatly advanced through the backup of the science while it is clear that the technology did not advance on reductionism alone.

While the opposing relationships such as science for recognition vs. science for design, analytical method vs. synthetic or integrating method, or science vs. engineering are being discussed, we are witnessing recent pursuits of new sciences that are different from reductionism.

In this lecture, we will focus on the role of synthetic or integrating method, comparing with analytical method, in the basic research of science and technology. The importance of synthetic method is indicated in the process of basic research to create societal values, and a methodology of such synthetic research is discussed. Also, a new form of writing an original research paper is presented to describe the processes and contents of such synthetic research. The methodology of synthetic research presented here has been discussed in the practice of *Full Research* or *Type 2 Basic Research* at AIST since 2001[1]. The new form for papers has been actually deployed in *Synthesiology*, a new scientific journal launched by AIST in 2008[2].

2 New methodology for basic research

Researches are often categorized into the basic research, the application research, and the development research. Here, we categorize them into the following three types.

- *Type 1 Basic Research*: This is a research whose subject is nature. Unknown phenomena are analyzed by observations, experiments, and theoretical calculations, factual knowledge is accumulated, and then universal laws and theories are built. It corresponds to the pure basic research. The researches are normally conducted within one discipline; it is rare that it stretches across several different disciplines. The researches are driven by researcher's academic curiosity.

- *Type 2 Basic Research*: This is a research where societal value is sought by synthesizing and integrating knowledge from multiple disciplines. Knowledge of what research should be done is accumulated and the methodology is built. It is a similar type with the objective basic research and application research. The researches are driven by the researcher's desire to realize some societal values.

- *Product Realization Research*: This is a research to actually put a new technology in use in society by utilizing results and knowledge obtained from the above two types of researches and actual experiences. This type of research corresponds to the developmental research. The researches are driven by the will of researcher who wishes to actualize research results in society.

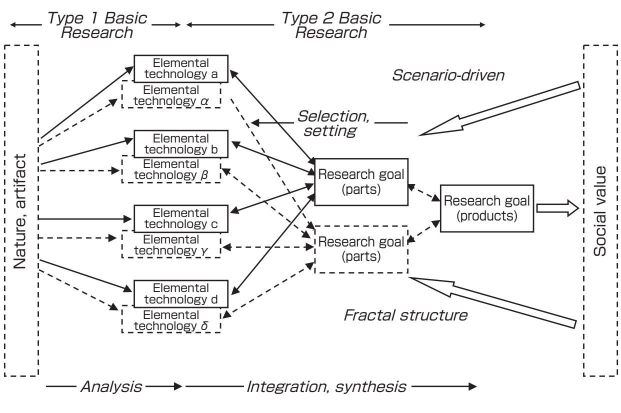


Fig. 1 Method of Type Two Basic Research

This paper is a draft of the lecture presented at the special session of the 3rd Conference of the Transdisciplinary Federation of Technology and Science on December 4, 2009. It is reproduced with the permission of TFST.

• *Full Research*: This is a research where the activities are conducted continuously and concurrently from *Type 1 Basic Research* to *Product Realization Research* with emphasis on the above *Type 2 Basic Research*. It is conducted often by a group or an organization. Individual researcher is normally in charge of some part of the *Full Research* series. Seen chronologically, a researcher may shift from *Type 2* to *Type 1 Basic Research*, or from *Type 2* to *Product Realization Research*, or he may be in charge of several types of researches concurrently.

Figure 1 shows the method of *Type 2 Basic Research* and also the relationship to *Type 1 Basic Research*. In *Type 2 Basic Research*, first, a research goal with societal value is set. Whether the research goal is close or not to the exit to society, its relationship to the societal value is stated clearly. Second, the research goal is broken down into research items expressed in the terms of science and technology, and then a scenario to address the items is set. After the setting of the scenario, what elemental technologies are selected for addressing the items is important. The selected elemental technologies may lie across several different disciplines. Third, the elemental technologies are combined, synthesized and integrated for the research goal to be achieved.

It should be noted here that there may be more than one scenario in such synthetic research to achieve the research goal. Several different scenarios may exist. It is also reasonable that the best scenario may vary depending on the researchers. It may be usual that researchers take into account several scenarios and, after comparing them, he/she chooses the best one. If the scenario is different, the elemental technologies selected will be different depending on the researcher.

The elemental technologies selected by the researcher are usually based on the results or conclusions already obtained in *Type 1 Basic Researches*. When trying to achieve a complex research goal, it is rare that necessary elemental technologies fall in one discipline. Rather, the elemental technologies are normally selected from multiple disciplines. While in some cases the existing elemental technologies can be applied to *Type 2 Basic Research* in its original form, in other cases the existing elemental technologies will be modified or improved. Also, if there is no appropriate elemental technology to fit the scenario, the researcher or the research group may return to *Type 1 Basic Researches* to obtain new elemental technologies necessary to achieve the research goal.

Table 1 Characteristics of Type One and Type Two Basic Researches

	Type 1 Basic Research	*Type 2 Basic Research*
Method	Analysis	Synthesis, integration
Action	Discovery, clarification	Invention, creation
Range of subject	Single discipline	Multiple disciplines
Uniqueness of solution	Exclusive solution	Multiple viable solutions
Drive power	Academic curiosity	Realization of social value
Important property	Adequacy of logic	Usefulness of solution
Originality	Dramatic advancement of solution	Uniqueness of method
Novelty	Novelty of solution	Novelty of method
Evaluation method Viewpoint of evaluation	Peer review Consistency, dramatic advancement	Merit review Usefulness, uniqueness

When a certain result is obtained by conducting *Type 2 Basic Research*, one cycle is completed upon evaluating how much the initially set research goal has been achieved. *Type 2 Basic Research* will continue to progress toward the exit to society as it repeats the cycles. Then the conclusions obtained in the previous cycle are carried over to the next cycle. The *Type 2 Basic Research* follows the above cycles in all cases, and is thought to have a fractal structure whether the research goal is big or not. Various characteristics of *Type 2 Basic Research* described above are shown in Table 1 in comparison with *Type 1 Basic Research*.

3 Returning the research result to society

Figure 2 shows the process by which results of basic researches are returned to society. In the modern society public funds are provided to basic researches of science and technology. The public funds are entrusted to research institutions reflecting the sponsor's will, and researches are made by the researchers under contract. The research results are written up as original research papers by the researchers and submitted to an academic society of the discipline. The paper undergoes a peer review or a process of anonymous evaluation by researchers of the same field. If it is accepted, it is published in an academic journal and contribution of the researchers to the academia and knowledge is recognized.

In reality, modern science and technology are finely segmented into many disciplines. Usually an academic society is organized for one segmented discipline, and the society has its own academic journal. The more

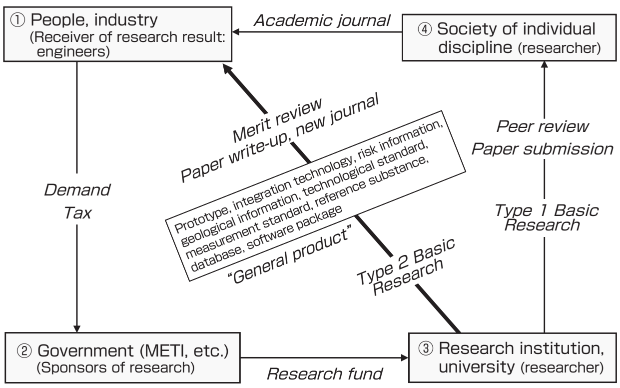


Fig. 2 Cyclical process of research in the society

the disciplines are segmented, special terminology and knowledge are necessary to be able to read and understand the papers. So it can no longer be easily understood by other people of the general society who may wish to utilize the research results. It is also often difficult for researchers of other disciplines.

Since publication of original research papers in an academic journal is the most basic requirement to a researcher, the researcher works full force to write such papers. Particularly, since a paper will not be published in an academic journal unless the research result is deemed valuable by peer reviewers or researchers of the same discipline, the author of a paper often writes primarily to get assent of researchers of his/her own discipline. The more the researcher engages in such efforts, the papers become more incomprehensible to researchers of other disciplines and general engineers. Many recent academic journals have been published worldwide and the number of papers being published is skyrocketing. But there is no change in the situation where the results of the basic research done by public funding are not returned directly to the sponsors.

There are some researchers, however, who provide the results directly to society and industry without going through the academic societies of the individual discipline. For example, when developing a prototype of products in a joint research, this will be an excellent opportunity for the research institute and the company to share the research results. Also patent, risk information, geological information, document standards, measurement standards, reference materials, and software package may be delivered directly to the users without going through the academic society.

These results are representative of the *Type 2 Basic Research* being highly valuable from the point that they contribute directly to society. However, these activities are apt to be taken lightly as mere sideline work of the main research activity. Moreover, there is no established methodology or medium to describe the results of *Type 2 Basic Research* as an original research paper. We believe there is great significance in evaluating the processes and results of the *Type 2 Basic Research* as valuable, in developing a new form of original research papers, and in issuing a new academic journal as a place for publication.

4 Development of a new form of research papers

It is commonly accepted today that writing an academic paper on the process and content of the research conducted and contributing it to an academic journal is something done routinely by researchers. A researcher who does not write any papers is unthinkable, and such a person is not evaluated as a researcher proper. However, one may realize that the research papers of science and technology that we are used to write have an extremely limited form.

The origin of modern science arose in 17th century Europe, and the method of science thereafter incorporated positivism to investigate whether a certain phenomenon is true or not. When a researcher writes a research paper, sufficient information must be described to enable other researchers to do a follow-up test to investigate whether they can obtain the same result described in the paper. Then the researchers investigate the logical relationship among the phenomena confirmed to be true and establish laws and theories.

In the modern research papers of science and technology, items unrelated to the "objective" phenomenon such as why the author started the research, what motivation and intention the author had, or why the author made a certain decision are not included. Even if such items are described a little bit in a paper, they are not subjects interesting in the peer review. The reason is because, in *Type 1 Basic Research* whose priority is the accumulation of factual knowledge, the descriptions of "objective" phenomenon are important, and those alone are sufficient. On the other hand, in *Type 2 Basic Research* where a selection is made among several equivalent scenarios with the research motivation being the realization of a societal value, the most vital part of the research cannot be expressed just by describing the "objective" phenomena.

A table of typical content of *Type 2 Basic Research* paper is shown in Table 2. The processes of *Type 2 Basic Research* methods shown in Fig. 1 are arranged in the order of research conducted. The originality of paper is represented by the uniqueness of the set scenario and the novelty of the integration and synthesis process of elemental technologies. Even if the same research goal is given, researchers will set different scenarios. They also take different processes of synthesis and integration if different elemental technologies are selected. Thus these are unique to individual researcher, and they represent the researcher's "originality".

It is not necessary to repeatedly describe details of the elemental technologies in a *Type 2 Basic Research* paper.

Table 2 Contents and features of *Synthesiology* papers

Structure of paper

1	Setting of research goal
2	Social value of research objective
3	*Proposal of scenario and selection of elements*
4	*Relationships between elements, and their integration and synthesis*
5	Evaluation of results and future developments

Characteristic of papers

Originality	・Set scenario ・Selected elements and methods of integration and synthesis
References	・Results of *Type 1 Basic Research* should be included in references

Since it is supposed that details are already published as the result of *Type 1 Basic Research*, they can be listed in References and only the conclusions need to be described.

5 Publication of a new academic journal *Synthesiology*

A new form of original research papers and instructions for authors were set, and then a new academic journal *Synthesiology*[3),4)] was launched in 2008. The titles of research papers published in Volume 1, Issue 1 are listed below.

- Mass preparation and technological development of an antifreeze protein
- Development and standardization of accessible design technologies that address the needs of senior citizens
- A challenge to the low-cost production of highly functional optical elements
- A strategic approach for comparing different types of health risks
- Technologies for the design and retail service of well-fitting eyeglass frames
- Improving the reliability of temperature measurements taken with clinical infrared ear thermometers

The keywords such as mass preparation, standardization, low-cost production, assessment strategy, design and retail service technology, and reliability improvement found in the titles were seldom used in conventional academic papers. The typical characteristics of *Type 2 Basic Research* is represented well.

The review of papers of *Synthesiology* is not a peer review that is done by researchers of the same discipline with the authors, but is a merit review that is done by a researcher of roughly similar field to the author's one and another from a totally different field. The merit review is done from the viewpoints shown in Table 1.

As one of the features of *Synthesiology*, discussion between the authors and the reviewers appears after the text of paper. The names of reviewers are also disclosed. Since the form of paper for *Type 2 Basic Research* is not finalized as of now, we decided, in solidifying the form, that it would be useful to publicize the discussions between the authors and the reviewers. We receive many comments from the readers that this discussion is very new and interesting.

It has been almost two years since the launch of *Synthesiology*, and we have noticed several points after publication. First, many authors commented that they were able to write the things that could not be written in conventional academic journals even if the authors had wanted to do so. Researchers seem to hope that the background and reason of research and the scenarios they employed in executing their research are publicized. They also have positive attitudes toward communicating more about that with other researchers.

Next, the reviewers commented that the originality of research become manifest in their scenarios most easily. On the other hand, the ways of synthesis and integration of elemental technologies are diverse. It is difficult to settle upon some uniform style at this point, but it is expected that some categorization of scenarios will eventually emerge. The point most reviewers found surprising was that they were not only able to understand the content of an original research paper written by researchers of different disciplines, but were able to give comments to the authors at a certain level of quality. This is a major characteristic of *Synthesiology* that would have never occurred in current academic journals dealing with *Type 1 Basic Research*. Thus there is a possibility that the journal would be accepted by a wide-ranging readership.

The readers have sent us many comments pointing out the advantages and usefulness in understanding and knowing about researches in fields outside of their own disciplines.

In this modern times when many complex issues such as global environments emerge and new industry-government-academia collaborations such as open innovation are suggested, we believe the methodology of synthetic research will play an important role along with *Synthesiology* that is a medium for its expression and a place of information exchange.

6 For further discussion in the symposium

Usefulness in the society is emphasized in the synthetic researches. However, the science was already expected to be useful at the beginning. The philosophy of natural science research in which we currently engage started with Francis Bacon, who stated that the humankind will become happy by studying nature and making discoveries and inventions[5)]. At the same time, the natural science took the route of positivism, and academic journals were established as their method. Then the emphasis was placed on the investigation of factual knowledge. On the other hand, the research community has never worked on the investigation method for usefulness that was expected by Bacon. However, the society expects “major discoveries” and “great inventions” by science and technology. One of the criteria evaluating such values is certainly usefulness, however the evaluation of usefulness is not simple. From the perspective of impact on society, one can evaluate a research result in terms of how much effect it has on the market. But the market dynamics is often moved by factors different from those of science and technology, such as protection of vested interests and industries, trendiness, and price competition. Due to these factors, the evaluation in the market cannot be fixed without the test of time. Therefore, measuring usefulness according to the impact on the market is not necessarily appropriate.

When the result is sent out to society by conducting synthetic research, there may be some cases where the elemental technologies are put together without a definite aim, and there may be other cases where the elemental technologies are synthesized with thorough think-through. The ones that are synthesized without a definite aim might sometimes work very well, but most of them will probably not yield good results. A good think-through is mandatory to produce usefulness and other values. The way or process on which research is done is called "scenario" in *Synthesiology*, which we ask the authors to describe in the papers. However, how to consider usefulness or what the scenario should be to realize such usefulness has not yet been very clear to us.

As a joint project of the Transdisciplinary Federation of Science and Technology, the Institute of Statistical Mathematics, and the National Institute of Advanced Industrial Science and Technology, we invited Dr. Yoshiyasu Tamura (ISM), Dr. Tatsuji Hara (The University of Tokyo), Dr. Atsuo Kishimoto (AIST), and Dr. Naoto Kobayashi (Waseda University) as panel members to have a general discussion on this subject. First, Dr. Kishimoto will explain the risk assessment of chemical substances as a specific example of synthetic research, to introduce to the audience and panel members a *Synthesiology* paper. Dr. Hara will speak on "synthesiology" from the perspective of knowledge integration. Next, we discuss about what the usefulness of research is and how usefulness is described, and how to evaluate the scenario to link scientific research to societal values. Dr. Tamura will speak about the modeling and simulation technology as tools for scenario building and usefulness evaluation. Dr. Kobayashi will propose an idea on what types of scenarios were put to practice with the papers published in *Synthesiology*, and the categorization of scenarios will be discussed. Based on these discussions, the meaning of describing interdisciplinary integration of knowledge as activities of researchers, and the future direction of the activities for giving values to research in society will be investigated.

References

1) H. Yoshikawa and K. Naito: *Sangyo Kagaku Gijutsu No Tetsugaku (The Philosophy of Industrial Science and Technology)*, The University of Tokyo Press (2005) (in Japanese).
2) http://www.aist.go.jp/synthesiology/
3) H. Yoshikawa: A journal of original papers of *Type 2 Basic Research*, *Synthesiology*, 1 (1), 1-6 (2008).
4) *Synthesiology*, 1 (1) (2008).
5) M. Akamatsu and H. Iyama: Science and society, or research institution and journal: A historical retrospection, *Synthesiology*, 1 (1), 59-65 (2008)(in Japanese) (*Synthesiology* English edition, 1 (1), 61-67 (2008)).