Roundtable talk to commemorate the fifth anniversary of the publication of *Synthesiology*

New research method in the age of science, technology, and innovation

— On synthetic approach in basic research —

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In the R&D for creating a product or business, the approach is taken where the necessary elemental technologies are integrated to achieve the goal, while many basic researches are driven by intellectual curiosity. On the other hand, in the R&D conducted using public funding, basic and fundamental researches that cannot be done by private companies are expected, as well as production of results that will benefit society and bring forth innovations to society. On the fifth anniversary since the launch of the journal *Synthesiology*, experts of the fields convened to discuss how the high expectation of basic and fundamental researches should be met, the significance and potential of the synthetic approach addressed by *Synthesiology*, and the direction of science, technology, and innovation in the future.

***Synthesiology* Editorial Board**
Translated by the editor

List of Participants

Tateo ARIMOTO	Director-General, Research Institute of Science and Technology for Society, Japan Science and Technology Agency
Yuichiro ANZAI	President, Japan Society for the Promotion of Science
Hiroshi KUWAHARA	Former Member, Council for Science and Technology Policy
Ayao TSUGE	President, The Japan Federation of Engineering Societies
Michiharu NAKAMURA	President, Japan Science and Technology Agency
Kazuo FURUKAWA	Chairman, New Energy and Industrial Technology Development Organization
Hiroyuki YOSHIKAWA	Director, Center for Research and Development Strategy, Japan Science and Technology Agency (Senior Advisor, AIST; Editor, *Synthesiology*)

Moderator: *Synthesiology* Editorial Board (Motoyuki AKAMATSU, Senior Editor)

Akamatsu

We launched *Synthesiology* in 2008, as a journal to provide knowledge for the integration of the science and technology to shape the results of R&D into a form usable in society. Five years have passed since its first publication. First, Dr. Yoshikawa, will you please talk about how *Synthesiology* was born?

Yoshikawa

In the academic societies for engineering, there have been long discussions on whether “synthesis can be written up as a thesis.” Although there were thoughts that “a paper cannot be written just by making a new machine” or “engineering cannot exist with only analysis,” we did not know what synthesis was. However, when I joined AIST in 2001, I was surprised to meet a group of 3,000 researchers who were conducting synthesis as a motto. They were engaged in research that couldn’t be shaped into papers in the traditional sense. I set a rather realistic goal of creating a journal where the researchers can submit papers on synthesis, and to have this recognized as an academic journal. Although a “thing” can be made, the methodology for making the “thing” does not remain, and historically, synthesis could not be transferred to the next generation. Making a journal was a challenge for leaving such efforts to the future, just like the so-called analytical academic journals. For the name of the journal, Dr. Akamatsu suggested “synthesiology” as a combination of “synthesis” and “logy.” The term synthesiology is gradually becoming accepted. However, there is still no conclusion on how synthesis contributes and develops in science and technology for the sake of humankind, and I think the mission of *Synthesiology* is extremely important.

Akamatsu

The issue is what must be done to bridge the gap between *Type 1 Basic Research* and *Product Realization Research*. The investment of funds into public R&D plays an important role to solve the global issues and to promote innovations through such basic researches. Since we have here today, people with experiences at the funding agencies and corporations, please discuss whether it is sufficient to go

on with the conventional methodology, or more effective to introduce synthetic research.

Do you think synthesiological thinking is useful in planning and preliminary evaluation of an R&D project?

Is synthetic approach effective?

Tsuge

Before the discussion of whether synthesis can be written as an academic paper, I will speak from the stance that an innovation leads to social and economic values, and that synthesiology is "practical." Looking at the GDP from 1995 to 2010, Japan's GDP is flat while the world has doubled, and Japan has clearly been left behind in the continuous developing world. I think there are many reasons for this, but one of them is that the national investment in science and technology has not led to innovation. At what kind of innovation are we aiming? Rather than the catch-up style of the 20th century, we are aiming for the extremely difficult front-runner type innovation. This requires individual creativity to generate the state-of-the-art science and technologies, and integration ability where these are integrated and then converted into socioeconomic value. Both of these abilities and human resources are essential, and I regard the social utilization of synthesiology as specifically the "integration ability" and "human resources."

Industry is responsible for innovation and training; national institutes for R&D, training, and education; and universities engage in education and basic research. Each part needs to create values, clarify the flow and interface of the players, and make full commitment. I think we have fallen into a mechanism where these are lacking and therefore science and technology do not lead to innovation. I think the importance of the role of synthetic approach lies there.

Akamatsu

What is your specific image of people as the interface?

Tsuge

I think there are two participants: the researcher in charge of research and the coordinator. Currently, the government is trying to build up a group of professionals called research administrators. Although coordinators and research administrators may not be able to write papers, they do contribute to social and economic values. Such professionals should be evaluated in society.

Dr. Ayao Tsuge

Kuwahara

I am confident that a "synthetic approach is effective" and I'd like to indicate two fields of its application. One is that when an R&D project involves system development, it could never be realized with a single technology, and it involves "how to combine several technologies in which order, how they should be harmonized, and how they are finally shaped into a final system structure." Therefore, synthesis thinking is mandatory as the objective and realizing processes are clarified, managed, and finalized through intermediate evaluation. Although some companies may still be inexperienced, the chances for success are higher for the projects where this process is done properly. Another field is that in the case where the R&D project is an individual science and technology development, the usefulness of synthetic approach also is high in positioning the research for the future, determining how widely it should be studied for, and clarifying the necessary human resource, even if at the time the objective is vague. The synthetic approach in these two fields will probably fuse into one eventually. I hope that by overviewing the whole in the process of reviewing the synthetic approaches in the two points, we will go in the right direction without missing out anything.

If I may add a point, I want to divide basic research into one based on intellectual curiosity and one to be a part of realizing innovation. I think a strong scenario is harmful for the former, but for the latter, a clear scenario must be made for outlining the objective and the synthesis process needed, the possible selection process in the intermediate evaluation, the prediction of other new key technologies that may be necessary, and for ways to hand them over to the people responsible for future innovation.

Akamatsu

Aren't the researches at New Energy and Industrial Technology Development Organization (NEDO) characterized by setting objectives to nurture innovation, and the necessary developments conducted to achieve the objectives?

Furukawa

I studied *Synthesiology* and thought it was a really innovative concept. Reflecting on why we were able to continue our efforts without being cognizant of *Synthesiology*, I think it was because we were trying to catch up with overseas research over the past 40 years, which overwhelmingly involved analysis rather than synthesis. Synthesis became

extremely important when we caught up and subsequently tried to overtake overseas research. At the same time, we recognized the importance of setting goals and objectives. I was somewhat shocked that such words came from basic researchers. I think basic and applied research should be done by the Japan Society for the Promotion of Science (JSPS) or Japan Science and Technology Agency (JST), and the mission of NEDO is to nurture research results into practical applications in industry. In that sense, the concept of *Synthesiology* is extremely important for NEDO, and we realized that this concept must be examined from the systems side.

Tool to join the last sentence of the paper and the goal

Nakamura

JST is positioned slightly closer to universities rather than being at the midpoint between industry and the university researchers who engage in basic research based on free, intellectual curiosity. However, it links them to social and economic values by overcoming the valley of death, and it advocates the "virtual network laboratory." This means a virtual laboratory is created by gathering the best researchers of Japan or the world for a fixed period. There, the basic research that "matches the strategic goal," as described by the government, is done, and the results generated is thrown directly to industry. When the result is brought to a company, new issues will emerge, and this is fed back to the goal-oriented basic research to form a spiral-up structure. The strategic goal is considered by the Center for Research and Development Strategy (CRDS) as a strategy proposal where the direction of science and technology innovation and the issues to be solved are considered. The strategic decision is made by the Ministry of Education, Culture, Sports, Science and Technology (MEXT). If a mistake is made at the lift-off, major problems may emerge in five or ten years.

The work of JST actually starts from allotting the strategic goal to the research disciplines. However, rather than considering "it may lead to some social and economic values if successful," the work tends to look at the world trend or at the authorities and the academic societies that say "this is important." Therefore, creating a scenario is a must. The basic research deals with results that may be highly uncertain and may only be significant in the distant future, but we must spend effort to create a scenario or vision at the starting line, and improve it as we go. I would appreciate it if *Synthesiology* becomes a usable tool as a methodology for starting up and designing a research project and for creating the scenario; or becomes a common tool that can be shared widely.

Dr. Michiharu Nakamura

Akamatsu

Does this mean "the proponent must write a scenario" when applying for a JST grant?

Nakamura

It is not that way right now. The final sentence of the paper is always, "In the future, this will become clarified and it will benefit the health of humankind." However, the statement is far distant from the actual research, and only the final sentence is written in the word of society. We are not making the effort to make the link. I think we must continuously think about the linkage to society even if one is engaged in basic research, but currently, there is no linking tool.

Funding and innovation

Akamatsu

I would like to move on to the topic of intermediate and post-facto evaluation of the R&D project. Dr. Arimoto, you have managed several projects, haven't you?

Arimoto

There are several points to be considered: In what position the funding programs and the individual projects that are run under such programs are in the innovation ecosystem of entire Japan and the world. Next, in which direction of society and market the innovation is going in the long timespan, where it is now, and whether this awareness for the position is shared by program directors (PDs), program officers (POs), and principal investigators (PIs) from the starting phase. Concerning these points, I have doubts whether they are being considered and shared.

However, there are distinct differences between evaluation and management methods for the blue-sky and mission-oriented research programs. Interference of management with the blue-sky research may be inappropriate and is often rejected, but I think it should be managed properly when the research begins to bear a mission. When I became in charge of the Research Institute of Science and Technology for Society (RISTEX), JST, funding programs were for scientific paper production, differing from the founding principle of RISTEX. I thought we should experiment, and conducted activities such as selecting POs and working on application

conditions always thinking about the shift of emphasis to social implementation. If social implementation is mentioned continuously, the applicants must think outside of the conventional style, and think about how the research team should be built, how to conduct social experiments using results, or how to bridge science and societies accordingly. I certainly think this is a form of synthesiology.

Akamatsu
You must evaluate whether the R&D conducted is appropriate within the process and interfere. However, once the project starts, isn't it difficult to interfere?

Arimoto
Yes, that is true. However, at RISTEX, the principal investigators and the research teams have been changed in several projects. Not just the individual research result and evaluation by project, but synthetic and panoramic analyses of management methods are done at the program level that is the upper level where the projects are concentrated, and this is reflected in the management improvement of the entire RISTEX. I think such interaction is extremely important.

Akamatsu
Doesn't Japan Society for the Promotion of Science (JSPS) conduct rather basic funding?

Anzai
Other than the goal-oriented research, there are sprouts of approaches that started from intellectual pursuits in various places, and I think spotting them plays an important role in innovation. Even if a topic is set by selecting a certain area, the sprout may spring up in some other field. There are infinite number of fields and the potential for science and technology is great. Nurturing the sprouts in these various fields is extremely important for a country like Japan that must work on innovation through its original efforts after it has past the "catch-up and overtake" stage. In relation to the talk today, JSPS must be a funding institute that nurtures sprouts in infinite fields and provides fertilizers so that the sprouts can grow on their own. These efforts are unspectacular because they are far from the market. Yet, the excitement of synthesis lies in the breadth of the science and technology topics and the wonders of innovations sprouting from totally different fields. To support innovation that may arise from such synthesis, I think we must till the fields, and need a stable and strong mechanism that allows sprouting.

Dr. Yuichiro Anzai

Another point I would like to mention is that "synthesis" sounds like project management for innovations, but I think innovations are generated from people. New sprouts are generated by enhancing the potential through the strong will of the developers, engineers, and researchers. To clarify why and how this is accomplished should be the direction of "science of synthesis."

Akamatsu
How should we judge what have become sprouts and what have become buds?

Anzai
I think the evaluation should depend on the objective of funding. For example, I am not for evaluating whether the results have been achieved in exactly two years with the small grants for young researchers or research encouragement offered by JSPS. I think the evaluation should be on how the person develops as a researcher over time. However, large funding cases must be evaluated strictly.

I think this may be the problem of the evaluation of government R&D funds, but the evaluation when applying tends to be strict, yet the interest shifts when evaluating the research results of the R&D to whether it can get the next grant. If the evaluation standard is unclear, the research that may sprout and the research that has an objective may be evaluated similarly. I think it is necessary to lay down a clear line, where basic research is evaluated on a long term basis and longitudinally, while the goal-oriented research should be evaluated on whether the result has been obtained in the eyes of industry and other sectors at the end of the research period.

Nakamura
I think JST must conduct different management according to the field and the phase. Particularly for the phase, quite a number of research topics are set in the beginning, and after two years, as the situation becomes clearer, JST has been cutting down about one-third of the researches. When cutting the researches, the reason is clearly delivered that "although the research is yielding excellent results, it departs from our objective." Then, we restructure the project.

Akamatsu
When you tell the researchers, "Your research departs from our objective," what kind of response do you get?

Nakamura

We receive significant response. The researchers are capable people who can do research in various places. However, we have many students and post-docs, and we have to let them go after giving them a year of a soft-landing period. We devise many ways to do so. However, we are conducting basic research for certain objectives, and within JST, we talk about emphasizing that point more.

Akamatsu

How about NEDO where the objectives are much stricter or more specific?

Furukawa

Since NEDO is an Incorporated Administrative Agency under the Ministry of Economy, Trade and Industry (METI), it takes a qualitative direction based on METI's policies. I think it is important how such a direction is incorporated into quantitative objectives and goals. We have engaged in projects of various scopes and budgets. Now, we have concentrated on national projects with greater direction, such as green innovation and life innovation. We conduct intermediate, post-project, and follow-up evaluations. Such evaluations can reveal ambiguity when initial project goals are set, and thus I feel these evaluations are extremely important.

In terms of the synthetic approach, the "four elements required for *Synthesiology*" are very important. These elements include; "R&D objective and social values," "scenarios for the introduction of research results to society," "selection and integration of the elemental technologies," and "evaluation of research results and future prospects." Although NEDO has its own evaluation frameworks, if this approach is implemented from the time of initial basic research and passed on to us, maybe we can more readily overcome periods of nightmares, valleys of death, or Darwinian seas.

In any event, rather than conducting evaluations using conventional methods, we conduct intermediate and final evaluations of issues relating to accountability and management in a strict manner to determine whether or not goals have been met or sufficiently achieved, and if the next direction is correct.

Dr. Kazuo Furukawa

Social mission of synthesiology

Yoshikawa

I think it is about how basic research projecs should be. The difficulty of research that is not curiosity driven will gradually become apparent, but beside that, there is no intention of creating a scenario for curiosity-driven research. In the *Mathematical Principles of Natural Philosophy* (Principia), Sir Isaac Newton described the hypotheses of the three laws, provided 500 pages of analysis, and proved that the hypotheses were correct. Meanwhile, *Synthesiology* is about the thesis on "why Newton proved the three laws." Setting up a hypothesis may seem to be one kind of scenario, but in general analytical research, there is no question about why a certain hypothesis is set up. When a certain interesting phenomenon occurs in nature, a hypothesis is offered about why such phenomenon occurs, and if it is proven, the thesis becomes a hit. In a research with an objective, a scenario that matches the objective must be written, and the objective is described in details. *Synthesiology* attempts to evaluate that point. However, this is not seen in other papers, and as Dr. Nakamura points out, the objective is simply written in the last sentence. In research with an objective, the last sentence should be investigated deeply, and the following question should be directed to the author, "Will your method realize the last sentence?" The paper is a presentation of the issue of what the goal-oriented research should be.

Tsuge

While this is not a direct answer to the topic raised by Dr. Yoshikawa, overlapping the issue of whether the idea of *Synthesiology* is academically valuable and the issue of the age of science, technology, and innovation, I think there is another social mission of *Synthesiology*. The birth of *Synthesiology* occurred due to curiosity-driven interest under the hypothesis that the result of the curiosity-driven basic research may be useful in fulfilling the social demands. I think the role of *Synthesiology* may be new, social-value-creating research through the fusion of disciplines and goal-oriented basic research based on original potentials. On the other hand, looking from the side of society, that itself does not lead to social value. Therefore, the entire process of bringing the research result to the market and social value must be architecturally designed, and *Synthesiology* should be the engine to propel this structure. We must work on these two issues.

Yoshikawa

In *Synthesiology*, the activities must be done so the project can be handed over to the people who will make the innovations. Unless sufficient consideration is taken for the

specific people who create the innovation and how such innovation will have an impact on society, a paper on the subject will be insufficient. Speaking rather radically, the starting point is curiosity. "Why does the heavenly body move?" "Will the earth come to an end tomorrow?" Both are curiosities. If one can explain how the heavenly body moves, that will be "good." However, if one finds out what will become of the earth tomorrow, that may be "bad," and action must be taken immediately, and this action may lead to a specific innovation. The actions that may be taken differ greatly according to the subject of curiosity. In the sense that research may lead to "then, what do we do?" situation, an action is not complete if the problem is only clarified. The application research begins from the point when the researcher finds the subject of application. Therefore, I am pointing out that everything arises from people's basic curiosity.

Akamatsu
What do you think about the question: while both curiosity-driven and scenario hypotheses are the same hypothetical investigations, aren't they subject to different thinking processes?

Anzai
This may be abstract, but it is a cause-and-effect relationship of "if this is done here, that may happen there." One will do something regardless of whether something happens or does not happen. This is a trial-and-error approach. In contrast, when one does something, and the result is considered good or bad; these are the two faces of cause-and-effect. Considering that a research is done from both ends, both contribute to synthesis.

Kuwahara
I would like to ask a question to Dr. Yoshikawa. Do you propose that *Synthesiology* itself should have individual value in a paper, or are you saying that a paper should be written synthesiologically to achieve ease of understanding and clarification of the origin of the paper?

Yoshikawa
This is a challenging point, but it is the former. While human wisdom has grown with massive scientific knowledge through the accumulation of fragmental scientific researches, manufacturing has not become gigantic knowledge. If manufacturing disappears, manufacturing will fade away socially. Science will not disappear but synthesis will. Humankind is unable to record the valuable thoughts during manufacturing, and this is a massive loss. One of the unfortunate results is making things that shouldn't be made because of lack of prior knowledge, thus destroying the environment. That is why people have to learn the basic knowledge of "this will happen when that is made." This is my basic motivation.

Kuwahara
How is *Synthesiology* useful in that learning process?

Yoshikawa
It is useful in clarifying the basic principle of how to make "things." To make some material, to make some system, or to make a social structure; these are all "making." When these are accumulated and used "to make" something new, the past experiences are utilized, and humankind will understand whether doing something will be good or bad for the earth. Currently, we are still repeating the process of making something new and finding out "it doesn't work."

Kuwahara
I think there are many "ways of thinking" about project management, where a project is started with an objective and brought to completion. Do you think that this way of thinking can be the subject of a paper?

Yoshikawa
I think a person who makes a "thing" may write a paper. It is said that a craftsman is expected to "steal the technique (from the master)," and this is the only way the craftsman can learn. This is because there is no record of how the master made a thing, the follower cannot learn how to make the product.

Kuwahara
Simply put, I think you mean synthesis should be described in all human behavior.

Yoshikawa
If the person who made the "thing" describes what went right and what went wrong in detail, the knowledge is accumulated, and humankind will become wiser. Currently, we have only the "thing" as a result. The proposal of *Synthesiology* is to objectively describe the process by which the "thing" was made.

Kuwahara
That is indeed valuable knowledge that should be left behind.

Arimoto
Dr. Naoto Kobayashi and others organized about 70 *Synthesiology* papers into three types: the aufheben, breakthrough, and strategic selection types. That was very instructive. I thought it was very useful in forming the framework of thought when setting up the mechanism for funding management or designing and realizing the scenario. I hope this effort continues.

Nakamura
In the sense of generating value in this world, I think such efforts are always taking a synthetic approach. For example, corporate research reports list the bottlenecks of the projects, but such information is rarely disclosed. If these are

accumulated and people can learn from them, I think they will be very useful.

Yoshikawa
If they are written and disclosed, that will be beneficial to humankind.

Tsuge
These reports are not disclosed not only because they are corporate assets and property, but because there is a mechanism in which such reports are not evaluated in the current academia. In that sense, the significance of starting *Synthesiology* is extremely great.

Human resource that can cause innovation

Akamatsu
I think human resource training is important. What do you think?

Tsuge
As an upper level issue of training human resources capable of the synthetic approach, there is no vision on the part of the trainers or the trainees, about which people should be trained or what kind of resource one wishes to become. This is also the greatest problem in training the science and technology human resources who bear the future of the nation based on science and technology creation. The teachers and the students or children must be able to see "who supports society" at an early stage of education. If this is done, one can study with the image of what one wishes to become.

If Japan were to survive with science and technology, I think at least four types of human resource categories are needed. First is type-D (differentiator) who carries the state-of-the-art technology. There are two of this type: one who is purely curiosity-driven and the other who has some social objective. Second is type-E (enabler technology) who generates technology that without it one may lose. Third is type-B (base) who has wide-ranging basic and fundamental technologies and skills. The fourth is type-Σ who integrates the types D, E, and B to generate socioeconomic value. I feel that the perspective of how to train the type-Σ human resource with generalization capability is lacking in the current science and technology policy and the educational policy. Therefore, this point must be made visible, and training must be done with the combination of education, research, and innovation policy. I feel that someone among the types D, E, and B who excels in one field may turn out to be an excellent type-Σ.

Akamatsu
I agree. Looking at the researchers around me, there are people with a good sense for synthesis even though they belong to type D, E, or B, and I have the impression that this ability may bloom when given the opportunity.

Kuwahara
I want to formalize this as follows. Synthesis is a field that stands alone as a discipline. Synthetic approach is totally different, but it is a method, and an extremely beneficial linkage to our society.

For innovation that is part of the whole, it is crystal clear that one must take the synthetic approach if one wishes to create an innovation. However, I feel there is vagueness of the definition of "what is an innovation." Innovation is "to achieve a totally new thing by breaking the conventional barrier." It is not remodeling or improvement of the conventional item. Also it should be understood that the word "innovation" contains in itself valuable outlet to our society. When we need to break the conventional barrier, we need creative and capable people. We must separate the education of such active people and the education for the people who passively join in innovation. I do not have much experience with the former, but we provide, in companies, opportunities of various experiences to selected prospective people, let them experience success and failure, and allow them to grow aggressive under severe world competition. This is a selective training. I think there may be another better educational method, but I cannot think of any yet. For the latter or the people who passively join in innovation, I hope they are correctly taught what an innovation is. In my understanding, innovation cannot be accomplished just by research results, but the government and/or companies that spearhead this effort must conduct necessary investments, plan so the investment return will be maximized, consider the acceptability of society, and finally realize innovation. Many people participate partially, and the project is successful only when the people who thoroughly understand innovation pour in their full effort. I think specific training for such people can be done, and I hope a certain format for their education can be laid.

Incidentally, we often hear about the necessity of making innovations happen in Japan, but there is no discussion of how many and what kind of innovations should be realized. Considering the national level including industries, several large scale innovations are necessary to solve the present

Dr. Hiroshi Kuwahara

economic difficulties. Selection is absolutely necessary for concentration, and the mechanism to study and determine such matters should be prepared by the government in collaboration with industries.

Akamatsu
What kinds of approaches are there when considering the human resource training for innovation at universities?

Anzai
At Keio University, we felt that there will be no future for Japan unless we educate innovative project manager, and started up the Department of System Design Engineering in the Faculty of Science and Technology, and created the Graduate School of System Design and Management (SDM). We are producing doctors from SDM, and the majority are students with work experience. As I mentioned earlier, to educate an innovative project manager, our objective is to provide training in system design, system management, system thinking, and communication abilities. It is essential to create a place of learning that nurtures the mind that can create innovation. We create a practical curriculum where people can learn through projects, by drawing a detailed design for educating people that are capable of producing new ideas, engage in teamwork, and can become team leaders. A team that combines people of humanities and sciences is created, and the courses are taught directly by professors that were involved in creating an innovation at companies. Considering the current state of Japan, merely discussing things is insufficient, and therefore we practice actual human resource training.

Akamatsu
I think it would be possible to train people in management at the graduate school level, but I also hear discussions about whether this capacity can be developed earlier.

Anzai
The study time of the middle layer of high school has reduced to half in the past 15 years, and in college, 70 % of the students spend five hours or less on studying per week. This is not the fault of the students but the education system. In the style of teaching en masse, the professor gives a one-way lecture from the podium, and the students earn credits if they write what they memorized for their final exam. When the students become used to this, come to graduate schools, become post-docs or go to companies, they cannot "be creative" or "be innovative." They must learn the basics of rational thinking by high school. Of course they need basic scholastic abilities, and the discussion for implementing the two is starting at the subcommittee for transition from high school to college of the Central Council for Education. This is extremely important. It is often said that the whole of Japan "is capable of doing what they are told but do not have the courage to initiate anything new," and this must be changed. There is an increased consciousness that this must be done from an early age. Whether this can be done will affect the future of Japan.

Arimoto
When I talk with the graduates and post-docs at the universities, I often get the feeling that they do not have sufficient understanding of where in a body of knowledge their researches are positioned or what relevance the researches have to society. On the other hand, at the management committee of a university, a student voiced, "Most of the professors give one-way lectures and do not tell us why the classes are important in history." I was struck by the fact that the young people are aware of the problem and have a sense of crisis.

At RISTEX, we are trying to use the keywords "researchers who move forward" and "managers who move forward," or human resources who go beyond and become the link between science and society. The antonyms are "researchers and managers who retreat inside." The dangerous ones are "researchers and managers who trample everything." Ultimately, we need to balance analysis and synthesis, and while analysis is the tradition of academics and is important, synthesis or the design and the systems are also important for innovation. During the International Year of Chemistry 2011, *Nature* did an article on "which direction chemistry should proceed in the future." They summarized: "There is analysis in chemistry, but synthesis also has been important historically. This may be the framework of thought and methodology that may allow chemistry to lead the other fields in the 21st century." I think the importance of synthesis is becoming recognized in various fields.

Another point is, when one wishes to create a major innovation, we must mobilize human resources with the knowledge of social sciences as well as of natural science and technology. There are many people who say they do not "wish to become involved in policy design" in economics, but I think that is exactly the most important point, and a mission-oriented fund should be created, so the social scientists can participate in solving the social problems. Unless such

Dr. Tateo Arimoto

structure is created, the social sciences are unable to work together despite various crises, and I fear there will be questions about whether they are of any use to society.

Furukawa

I think Japan's innovative direction may be towards the "realization of a hydrogen society." In terms of developing a hydrogen society, key points include a top-down approach for issues such as regulations and safety, as well as determining how to ultimately utilize batteries and fuel cells. Regarding fuel cells, we are conducting fundamental analysis at SPring-8 (Super Photon Ring-8 GeV) and J-PARC (Japan Proton Accelerator Research Complex), but in reality, we still do not really understand the behavior of fuel cells. The ability to carry out social synthesis at the top level and the analysis of cells at the molecular and atomic levels, I think, is the strength of Japan. There are many thoughts and ideas about hydrogen societies, and in this respect, one automobile company has committed to selling fuel cell vehicles at a price of about five million yen by 2015. I think it would be an innovative approach if our society as a whole moves in this direction, including innovations from the parts level to innovations in the structure of society.

Kuwahara

Your comment is extremely important. If the government spends maximum effort to build a hydrogen society, the focus of the research will become set. There are not too many big projects of the government, and many cannot be done. The government should raise this project as a candidate, and unless Japan shows the spirit of taking the lead in the world, even using the results from overseas if the Japanese R&D is insufficient, there will be no innovation. There are many people who think that the budget will be shifted away from them if such a decision is made. If it is stated, "This is not to exclude others. Major projects will be continued," then, we can include the "infinite number of fields" as mentioned by Dr. Anzai. Randomness will not generate anything.

Synthesiology is the stage for industry

Akamatsu

We have heard comments about how to conduct research, how to build organizations, and human resource training. Would Dr. Yoshikawa provide us with a general overview?

Yoshikawa

Recently, we are receiving submissions to *Synthesiology* from people of external universities, companies, and overseas, and I think this is a good trend. We received a difficult question from Mr. Kuwahara on what is the main concept of *Synthesiology*, but I am glad that you understand it now. Simply said, while science progressed mainly through analysis, most of human behavior has been synthesis. Although there were results of behavior and discussions on natural objects, when one tried to learn about behavior itself, an extremely academic new field called synthesis emerged. In fact, because the majority of industry is synthesis, the importance of synthesis is extremely high. I think we obtained consensus that a journal that addresses this is good.

There was a comment on what human behavior is and that it is"innovation." It was indicated that the innovation promoter must understand the receptivity of the bearing body or society, whether it will be beneficial to the body, and what the ecosystem is that makes up this innovation. These are very important, and individual activities are all synthesis. In that sense, the point of *Synthesiology* must be how to create an ecosystem where innovation can take place, rather than creating one product. This leads to the policy debate as discussed before, and it must spread further in the future. Aside from whether this journal will be able to spread it or not, I feel that it is a massive proposal of the issues including such topics. Then, the matter of funding and the evaluation of research results in terms of how synthesis is to be studied become quite important. JSPS, JST, NEDO, and RISTEX take different stances, but isn't the evaluation of the synthetic ability important for funding? Getting down to realistic issues, I really hope you provide lots of research funds to people who submit papers to *Synthesiology*.

There was a discussion about "nurturing people." Although innovation is inside people's heads, there is a lack of awareness that it must be handed over to the next generation. If humankind becomes extinct because of environmental problems, it means that humankind has failed to become smart over the ages because the transfer over generations of the knowledge of making "things" and modifying nature was extremely insufficient, despite the vast analytical accumulation. There is a deep relationship between the transfer of the processes and nurturing people, and there are many problems that must be reconsidered in education. I thought the suggestion that what kind of human resources should be nurtured is one effective approach when considering *Synthesiology* or synthesis is important.

Also, Mr. Furukawa talked about the realization of the

Dr. Hiroyuki Yoshikawa

hydrogen society as a Japanese innovation. Small innovations are of course necessary, but we would like to see one or two national level innovations. During the period of rapid economic growth when Japan was successful, there were 250 million Europeans, 200 million Americans, and about 100 million Japanese in terms of market and supplier of products. Therefore, about 100 million people out of about 550 million worked hard and rejoiced in victory. Now, the world population has reached nearly 8 billion, and they are the suppliers and market of industry. Five hundred million became 8 billion or it increased more than 10 times. As such qualitative changes occur in the competition, what is the superiority of "small" Japan. There are many. We have many excellent basic researchers, as well as nanotechnology and materials technology through basic research. These are the foundations of technology born during the period of rapid economic growth. They may be production technology, machine tools, or basic design methodology. If one wishes to do business using them, the market expands immensely. In fact, we are at the threshold of opportunity, and one should apply the *Synthesiology* way of thinking. I think it is "to carefully do analysis of the background of what the government should do," as Mr. Furukawa and Mr. Kuwahara pointed out. When the CRDS creates a research program, we say we must consider which way the research direction should go. Also, a leader is necessary. I believe the leader is industry. In other words, with *Synthesiology*, it is now the stage for industry.

Akamatsu

We were able to hear various insightful comments on the future research methods, and this talk was highly appropriate for commemorating the fifth anniversary of *Synthesiology*. Thank you very much.

This roundtable talk was held at the Annex Building, Tokyo Headquarters of the Japan Science and Technology Agency in Chiyoda-ku, Tokyo on October 3, 2012.

Dr. Motoyuki Akamatsu

Profile of Participants

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Completed the master's program at the Graduate School of Science, Kyoto University in 1974. Joined the Agency of Science and Technology in 1974. After serving as the Deputy Director-General, Science and Technology Policy Bureau, was appointed as the Director-General, Science and Technology Policy Bureau, Ministry of Education, Sports, Science and Technology (MEXT) in 2004. Director-General, Research Institute of Science and Technology for Society(RISTEX),, Japan Science and Technology Agency (JST); and Deputy Director-General, Center for Research and Development Strategy, JST in 2006. Concurrently, Professor, National Graduate Institute for Policy Studies from 2012. Acts as the key figure in the policy-making for science and technology in Japan. Recently, works to develop a new funding system for problem-solving research for practicing "science for society." Books and articles include: "Science and Technology Policy" (by T. Arimoto, in *Have Japanese Firms Changed? The Lost Decade*, Palgrave Macmillan, 2011); and "Rebuilding Public Trust in Science for Policy Making" (by T. Arimoto and Y. Sato, *Science*, 337, 1176-1177, (2012)).

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Born 1946 in Tokyo. Completed the doctor's program at the Graduate School, Keio University in 1974. Visiting Professor, Carnegie Mellon University; Assistant Professor, Faculty of Letters, Hokkaido University; and Professor, Faculty of Science and Technology, Keio University. Head, Faculty of Science and Technology, Keio University, 1993~2001; and President, Keio University, 2001~2009. Currently, President, Japan Society for the Promotion of Science; and Executive Advisor for Academic Affairs, Keio University. Also acting as Chairman, University Sub-Council, Central Council of Education, MEXT; Chairman, Committee for Promotion of Learning Innovation Previously worked as Chairman, Japanese Association of University Physical Education and Sports; Chairman, Japan Association of Private Universities and Colleges; Chairman, Association of Pacific Rim Universities; Chairman, Information Processing Society of Japan; Chairman, Japanese Cognitive Science Society; and others. Books include: *Kokoro To No* (Mind and Brain) (Iwanami Shinsho); *Digital No Ga Nihon O Sukuu* (Digital Brain will Save Japan) (Kodansha); *Kyoiku Ga Nihon O Hiraku* (Education will Open Japan) (Keio University Press); *Ninshiki To Gakushu* (Cognition and Learning) (Iwanami Shoten); *Mondai Kaiketsu No Shinrigaku* (Psychology of Problem Solving) (Chuo Shinsho); and others. Specialties are cognitive science and information science.

Hiroshi KUWAHARA
Graduated from the Department of Electrical Engineering, The University of Tokyo in 1960. Joined Hitachi, Ltd. and became Director, Ohmika Works; General Manager, Electric Systems Division; Managing Director; Senior Managing Director; Vice President; and Vice Chairman. Former Member, Council for Science and Technology Policy. Served as the chairman of Hitachi Maxell, Ltd., Hitachi Cable, Ltd., and Hitachi Kokusai Electric Inc. Special Advisor, Hitachi, Ltd. Also acted as Executive Chairman, Council on Competitiveness Nippon; Chairman, Japan International Science and Technology Exchange Center; Chairman, Trans-disciplinary Science and Technology Initiative;

President, Satellite Positioning Research and Application Center; President, Global Water Recycling Reuse System Association, Japan; Vice Chairman, Japan Federation of Engineering Societies; and others. Currently, Senior Corporate Advisor, Hitachi Maxell, Ltd. and Hitachi, Ltd.

Ayao TSUGE
Born 1943 in Tokyo. Graduated from the School of Engineering, The University of Tokyo in 1967, and completed the doctorate in 1973. Doctor of Engineering. Completed AMP 101, Harvard Business School in 1987. Joined the Mitsubishi Heavy Industries (MHI), Ltd. in 1969 and worked on the R&D for nuclear power generation. Chief, Nuclear Power Research Promotion Division; Director, Takasago R&D Center; Director/General Manager of Technology Headquarters; and President and Managing Director/General Manager of Technology Headquarters. Fulltime Member, Council for Science and Technology Policy, Cabinet Office in January 2005; Special Adviser, MHI Ltd. in January 2007; and President, Shibaura Institute of Technology in December 2007. Member, Science Council of Japan; Vice Chairman, Engineering Academy of Japan; Chairman, Japan Federation of Engineering Societies in April 2011; and Chairman, Japan International Science and Technology Exchange Center.

Michiharu NAKAMURA
Completed the master's program (physics) at the Graduate School of Science, The University of Tokyo in March 1967. Obtained Doctor of Science degree with dissertation "The study of distributed feedback laser diode." Joined Hitachi, Ltd. in April 1967. Worked at the Central Research Laboratory; Deputy-Director, Hitachi Research Laboratory in August 1990; Director, Central Research Laboratory in August 1992; Director and General Manager of R&D, Hitachi, Ltd. in April 2001; Executive Vice President, April 2004; Fellow in April 2007; and Director in June 2008. President, Japan Science and Technology Agency in October 2011 (to present); and Member, Council for Science and Technology (to present).

Kazuo FURUKAWA
Joined Hitachi, Ltd. in 1971. President and Executive Officer in June 2006; Appointed Vice Chairman and Chief Executive Officer in April 2009, and Special Advisor in June 2009. Chairman New Energy and Industrial Technology Development Organization in October 2011. In addition, served as Vice President, Keidanren from May 2007 to May 2009; and Chairman, Information Processing Society of Japan from May 2011.

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Born 1933. Professor, The University of Tokyo; President, The University of Tokyo; President, Open University of Japan; President, AIST; and currently, Director, Center for Research and Development Strategy, Japan Science and Technology Agency. Also acted as Chairman, Science Council of Japan; Chairman, Japan Society for the Promotion of Science; Chairman, International Council for Science; and Chairman, International Academy for Production Engineering. Doctor of Engineering. Research of general design theory and general synthesis theory. Engages in design education and intelligent manufacturing system research based on the theories. Books include: *Honkaku Kenkyu* (Full Research) (The University of Tokyo Press, 2009); *Kagakusha No Atarashii Yakuwari* (New Role of Scientists) (Iwanami, 2002); *Techno Globe* (Kogyo Chosakai, 1996); *Technology To Kyoiku No Yukue* (Direction of Technology and Education) (Iwanami Shoten, 2001); *Robot To Ningen* (Robot and Human) (NHK Publishing, 1985); and others.