1

Fostering of Researchers and Education in Life Science

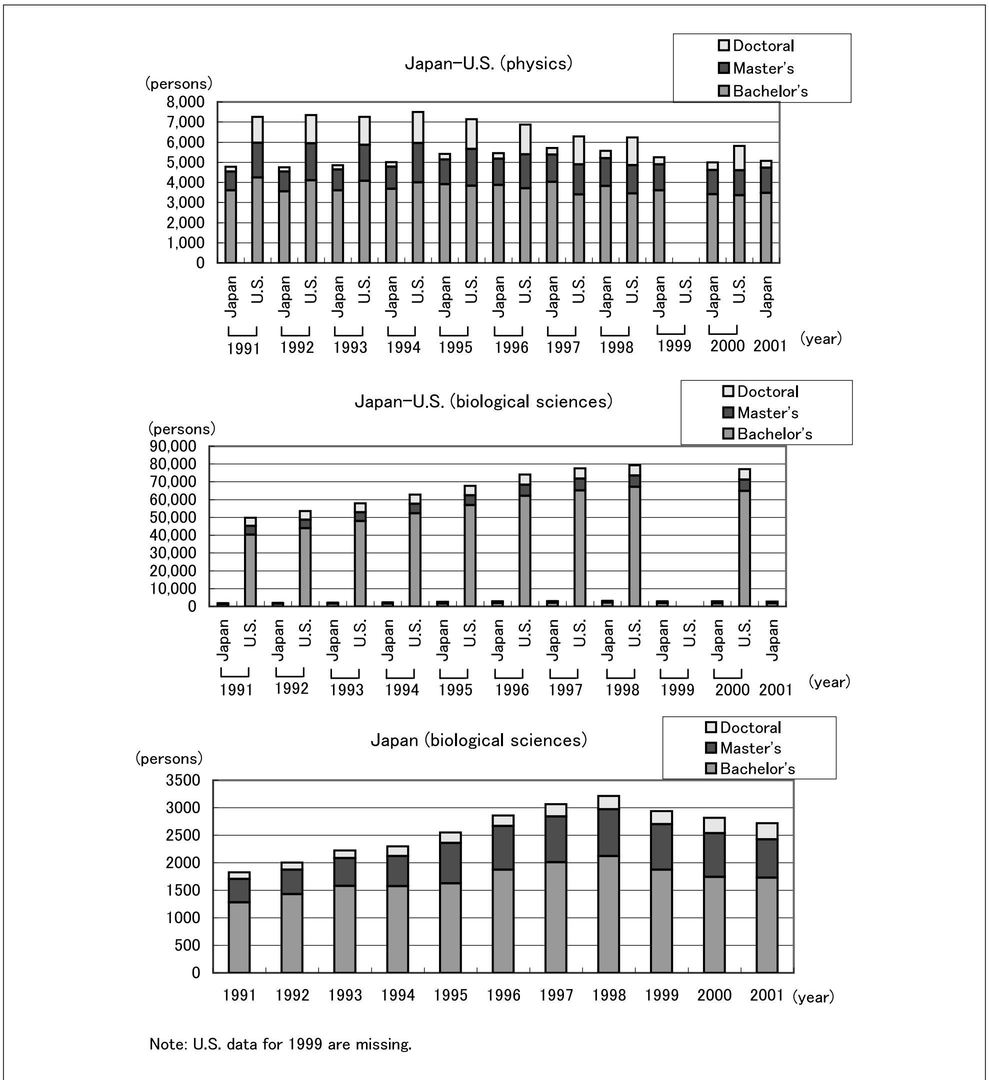
MARIKO SHOJI, SHIN-ICHI MOGI
Life Science and Medical Research Unit

1.1 Science and technology policy in life science

The 21st century has been called the "Century of Life." As that name implies, life science is the most watched and rapidly developing scientific field today, both in and out of Japan.

Life science comprises "comprehensive sciences and technologies that explain the complex and subtle mechanisms of biological phenomena and apply the results in fields such as medicine, the environment, food production, and industry. It is an important contributor to the improvement of national living standards and the development of the national economy (2002 White Paper on

Figure 1: No. of people receiving degrees in biological sciences and physics in Japan and the USA



Source: Japanese data is derived from "Physics" and "Biology" under "Science" in the Basic Survey Report on Schools. U.S. data is derived from "Physics" and "Biological Sciences" in the National Science Foundation's Science and Engineering Degrees: 1966-2000.

Science and Technology).”

In Japan’s science and technology policy, life science is positioned and advanced as one of four major fields in the Second Science and Technology Basic Plan (determined by the Cabinet on 30 March 2001). At the meeting of the Council for Science and Technology Policy in September 2001, the life science branches that in FY 2001-2005 should be given priority for promotion by Japan and their research goals were made clear.

In the FY 2003 science and technology-related budget,[1] the estimated budget request for the life science field is ¥209.1 billion, a 28 % increase from the year before. This is a large amount compared to the ¥128.8 billion for the information and communications field (an 11.5 % increase), ¥64 billion for the environmental field (a 26.2 % increase), and ¥23.1 billion for the nanotechnology and materials field (a 100.9 % increase).

Even as the budget expands, however, we must point out that there is a shortage of research personnel in life science. Regarding the status of researchers in life science, Figure 1 shows the number of people receiving degrees in physics and in biological sciences in the United States of America and Japan. Although these statistics do not give a complete picture because in the case of Japan only biological sciences are included and agriculture, pharmaceutical sciences, and medicine are excluded, there is a large gap between the two countries. In 2000, only 1/37 as many people received bachelor’s degrees, 1/8 as many received master’s degrees, and 1/21 as many received doctoral degrees in Japan compared to the USA.

The number of physics degrees awarded in the United States has been declining over the past several years. In 2000, there was no longer a large gap between Japan and the USA.

The Second Science and Technology Basic Plan says the following about recent issues in the life science field.

- To promote the life science field, the national government should promote increased understanding of the field among the Japanese people.
- Scientific and technological progress is having an increasingly great effect on human beings and society. As exemplified by bioethics, the ethical issues raised by science and technology are important ones.
- The number of issues of great concern to ordinary people, such as clinical trials, transplants, and regenerative medicine, is expanding. Bioethics is an issue that must be debated by the Japanese people as a whole.
- As life science and information science continue to develop, they will have great influence on individuals and on society. It is therefore essential to seek a social consensus and to create rules of ethics.

The plan includes the following strategies to promote the various branches of life science.

- From the perspective of bioethics, along with the promotion of advanced research in life science, it is necessary to obtain the understanding of a large majority of the nation’s people by strengthening the active sharing of information, education, public relations, and the exchange of ideas.
- To establishing and foster multidisciplinary human resources to support new developments in life science, universities and other research organs must flexibly adjust their education and research bases and organizations, and policies to advance high school science education must be adopted.

Regarding life science literacy, a February - March 2001 study of science and technology awareness (National Institute of Science and Technology Policy, NISTEP Report No. 72) included a survey of understanding of science and technology terms.

Regarding the word DNA, 74 % of people surveyed responded that they understand “well” or “fairly well.” This is a large increase over the approximately 20 % responding so in November 1991 survey and 45 % in February 1995. However, of those responding that they understand “well” or “fairly well,” only 28 % were able to correctly answer the question “Where is DNA found in the body?” The report stated that, “Understanding of science and technology terms is closely related to the frequency with which they are used in the mass media.”

Based on the perspectives above, this report will examine the following two points.

(1) The future development of life science requires sufficient funding, as well as further promotion of the development of researchers. This requires a reexamination of the university education system.

(2) The 21st century is the "Century of Life," and a long-term perspective requires increased life science literacy for society as a whole. This requires an examination of the role of education.

1.2 Fostering life science researchers in universities

Universities play the most important role in fostering researchers. Universities foster the human resources who will carry the field of life science into the future. To expand that foundation, an educational system that promotes life science is required.

During recent years in life science fields, research and development based in molecular biology, such as genomes and genes, have rapidly developed into the mainstream. The content of such research and development is multidisciplinary and often impacts society as a whole.

However, as has been pointed out in "Regarding the Promotion of Bioscience Research (Proposal)," a February 2000 report by the Science Council, current education and research systems in university and graduate school departments of medicine, pharmaceutical sciences, science, agriculture, and so on are unable to fully respond to such rapid innovative and multidisciplinary developments in life science. The report therefore suggested that life science teaching and research departments undertake improvements, including reorganization of existing structures, to provide systematic education in life science.

Underlying this report is the fact that when research in molecular biology began to flourish in the mid 20th century, science departments in Japanese universities did not necessarily become the home of such research and education. Instead, medicine, agriculture, and other departments often adopted such fields as methods for applied research. This is because when new disciplines such as molecular biology were born, science departments were not flexible enough to create space for them.

Aware of this problem, several national universities have formed graduate research departments integrating life science fields such as science, agriculture, pharmaceutical sciences, and medicine (see Table 1).

Professor Mitsuhiro Yanagida, dean of the Kyoto University Graduate School of Biostudies, says "The fostering of outstanding life scientists requires the establishment of life science departments at the undergraduate as well as the graduate level. The Life Science Research Faculty accepts graduates from departments such as science, agriculture, pharmaceutical sciences, medicine, and engineering, but that does create some confusion in graduate education. To produce outstanding life scientists, we must implement life science education at the undergraduate level." Further

Table 1: The graduate school of Life science in national universities in Japan

	Kyoto University Graduate School of Biostudies	Tohoku University Graduate School of Life Sciences	Osaka University Graduate School of Frontier Biosciences
Established	April-99	April-01	April-02
Structure	2 divisions, 13 departments	3 divisions, 12 departments	1 divisions, 7 departments
Features	Forms research groups in science, agriculture, medicine, pharmaceutical sciences. Fosters human resources who will utilize new life science for preservation of the global environment and human welfare and happiness, and who will understand various vital phenomena of living things as a systemic function, and pursue these systemic functions.	Integrates life science fields such as science, medicine, dentistry, pharmaceutical sciences, agriculture, and engineering. Undertakes extremely wide-ranging research and education, from the molecular to the individual level, with the aim of understanding, maintaining, and protecting biological systemic function.	Gathers life science related fields of medicine, engineering, science, etc. Undertakes research and education to elucidate how elements of life from the sub-nano scale to the cell level form living organisms through dynamic processes and these pervasive structures and principles give rise to biological functions.

Source: Authors' compilation based on university web seites

Table 2: Life science standards in the National Science Education Standards in USA.

Year	Content standards	Overview of guide to the content standards
Kindergarten-4th	Characteristics of organisms	The basic needs of organisms. The structures of plant and animal bodies in proportion to various functions. The signals of internal and external behaviors.
	Life cycles of organisms	The plant and animal life cycle of birth, development, reproduction, and death. Plants and animals resemble their parents. Many of characteristics in organisms are inherited from parents or result from interaction with the environment.
	Organisms and environments	All animals depend on plants. An organism's behavior is related to the characteristics of its environment. All organisms cause changes in their environments. Humans depend on natural and constructed environments.
5th-8th	Structure and function in living systems	All organisms are made of cells, the basic unit of life. Cells have many functions, and produce more cells by growing and dividing. Specialized cells form tissues, and tissues form organs. Human beings have systems for digestion, respiration, reproduction, circulation, excretion, movement, etc., and these systems interact with each other.
	Reproduction and heredity	Reproduction is a characteristic of all living systems, and is necessary to continue species. Many species combine ovums and sperms to produce new individuals. The new individual receives genetic information from its mother and father. Genetic information is included in genes. A cell of human may include hundreds of thousands of genes.
	Regulation and behavior	Organisms regulate their internal environments by sensing the internal environment and regulating physiological changes therein. Behavioral response requires regulation and communication at the cell, organ, and organism levels. A behavior of organisms evolves through adaptation to its environment.
	Populations and ecosystems	All individuals living together and the physical factors they interact with constitute an environment. Food webs describe the relationships among producers, consumers, and decomposers in an ecosystem. The number of organisms that can be supported by an ecosystem depend resources that can be used and on abiotic factors such as the amount of light and water, temperature range, and soil conditions.
	Diversity and adaptations of organisms	Millions of species of plants, animal, and microorganisms are alive today, and all organisms share a certain unity. Biological evolution accounts for the diversity of species gradually developed over many generations. Species extinction occurs when its environment changes and species characteristics are insufficient to ensure survival.
9th-12th	The cell	Each cell has a structure appropriate to its functions. Many cell functions involve chemical reactions. Genetic information stored in DNA is used to direct the synthesis of the thousands of proteins needed by cells.
	Molecular basis of heredity	In all organisms, the instructions for their characteristics are transmitted by DNA, which is composed of four subunits (A, G, C, T). Most human cells contain two copies of 22 chromosomes, and one pair that determines sex. Changes (mutations) in DNA occur spontaneously at low rates.
	Biological evolution	Species evolve over time. The diversity of organisms is the result of more than 3.5 billion years of evolution that has filled the available niches with life forms. The millions of species of animals, plants, and microorganisms now living on Earth are related through common ancestors.
	Interdependence of organisms	The atoms and molecules on the earth cycle among the living and nonliving components of the biosphere. Energy flows through ecosystems in one direction, from photosynthetic organisms to herbivores to carnivores and decomposers. Human beings live within the world's ecosystems. Humans are gradually modifying ecosystems as a result of population growth, technology, and consumption.
	Matter, energy, and organization in living systems	The chemical bonds of food molecules contain energy. The distribution and abundance of organisms and populations in ecosystems are limited by the availability of matter and energy and the ability of the ecosystem to recycle materials. As matter and energy flows through different levels of organization of living systems - cells, organs, organisms, communities - and between living systems and the physical environment, chemical elements are recombined in different ways.
	Behavior of organisms	Multicellular animals have nervous systems that generate behavior. Organisms have behavioral responses to internal changes and to external stimuli. Behavioral biology has implications for humans, as it provides links to psychology, sociology, and anthropology.

Source: Reference [2].

study of how to prepare graduate schools and other institutions for comprehensive life science education and research remains necessary.

As we have said above, life science will continue to have important impacts on society as a whole. Completion of curricula including relevant classes at the university general education level is also necessary. At the Massachusetts Institute of Technology (MIT) in the United States, for example, life science is a requirement for all students. This precedent-setting requirement has been widely discussed in the USA as well.

1.3 Life science literacy and education

Life science will be increasingly important in social communication. It is therefore necessary to attempt to raise the life science literacy of society as a whole. From a long-term perspective, education has the most important role to play in any attempt to increase scientific literacy.

Through the advancement of molecular biology, life science has developed systematic understanding of diverse biological phenomena and the mechanisms of life primarily through principles such as genetics. The future of life science will develop around those principles, and life science education must add such knowledge in developmentally-appropriate stages.

Here we will introduce recent education reforms in the United States and the United Kingdom, and the position of life science in those reforms.

• **United States of America** [2],[3]

In 1980 in the United States, the National Science Teachers Association (NSTA) began a major campaign regarding the so-called crisis in science education. Since then, academic societies, organizations such as the American Association for the Advancement of Science (AAAS), states, and communities have all taken individual actions to reform science education. In 1991, the NSTA asked the National Research Council (NRC) to coordinate the development of National Science Education Standards. Funds for the development of the standards came from the U.S. Department of Education and the National Science Foundation (NSF). The standards were developed with the participation of numerous science teaching organizations led by the NSTA and the AAAS, as well as government organizations. The standards were announced in December 1995.

Rather than what are commonly thought of as standards, the U.S. National Science Education Standards are intended as ideals and goals for science education that will enable all Americans to be scientifically literate during the 21st century. Scientific literacy is defined as "the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity."

National science education standards in the USA comprise the following six standards.

(1) Science teaching standards
  Facts that teachers of science at all grade levels should understand and be able to do.
(2) Standards for professional development for teachers of science
  Standards for science teacher's professional development and for the maintenance of the teaching profession.
(3) Assessment in science education
  Standards for determining the quality of assessment practices used by teachers and state and federal agencies to measure student achievement. Assessment is a primary feedback mechanism in the science education system
(4) Science content standards
  An outline what students from kindergarten to grade 12 should know, understand, and be able to do in natural science.
(5) Science education program standards
  Necessary conditions for high-quality school science programs.
(6) Science education system standards
  Standards for judging the performance of the components of the science education system as a whole.

Of these, (4) Science content standards provide points of emphasis and perspectives to help states and communities develop their own curricula. Science content standards comprise the following eight categories. [1] Unifying concepts and processes in science covers kindergarten through 12th grade (ages 6-18), while the other seven categories are each divided for kindergarten through 4th grade, 5th through 8th grade, and 9th through 12th grade.

[1] Unifying concepts and processes in science
[2] Science as inquiry
[3] Physical science
[4] Life science
[5] Earth and space science
[6] Science and technology
[7] Science in personal and social perspectives
[8] History and nature of science

In these, life science is one of the categories. Standards and guidelines for life science are shown in part in Table 2. The adoption of current developments in life science can be seen in, for example, "Biological Lifecycles" for kindergarten through 4th grade, which includes the concept of heredity, and "Structure and Function in Living Systems" for 5th through 8th grade presents life in terms of systems.

The interaction of science with society, a point that is vital to life science, is covered in [7] Science in personal and social perspectives.

• **United Kingdom** [4],[5]

Declining academic skills among students and academic levels that vary by community and school are serious problems in the United Kingdom (England and Wales), and active debate regarding reforms have been taking place since the 1970s. Concerning curricula, the establishment of national standards has been a point of contention, and national government bodies have made numerous public policy statements.

Based on the 1988 Education Reform Act, a National Curriculum (NC) for all publicly-operated schools was introduced. The NC was revised in 1991 and 1995, and the current version is a September 2000 revision.

Under the Education Reform Act, science, along with English and mathematics, is a required or core subject among the foundation subjects. Underlying the requirement that all children learn about science are an effort towards a shared national scientific literacy and society's need for preparatory education to respond to rapid changes in science and technology. In addition, the reforms are intended to efficiently produce human resources who can compete internationally using science and technology.

The NC is set as a ministerial ordinance, and includes content and goals for learning. However, the NC differs qualitatively from Japan's national curriculum in that students are evaluated through national tests based on the NC (external evaluation) as well as by teachers (internal evaluation), in that publicly-operated schools but not all schools are subject to it, and in it not being a complete school curriculum.

Under the NC, primary and secondary education are connected and integrated, with compulsory education divided into Key Stage 1 (age 5-7), Key Stage 2 (age 7-11), Key Stage 3 (age 11-14), and Key Stage 4 (age 14-16).

The NC includes goals and study programs in each subject. The study program for science includes "scientific enquiry," which covers skills (techniques and abilities) and attitudes; "life processes and living things," "materials and their properties," and "physical processes" which covers knowledge and understanding. In addition to natural science fields such as life science, the NC also includes study related to science and society and everyday life through concepts like "nature of science" and "science in an everyday context."

Life science is covered under "life processes and living things." As can be seen in Table 3, life science education in the NC is designed to be continuous and integrated, with categories increasing and content becoming more advanced as children move through the stages. Children also learn about health and the functioning of the human body here.

Increasing national scientific literacy is a goal of the science education reforms in the United States and the United Kingdom. To achieve that goal, science education has been reexamined from a long-term perspective, and the resulting new structure can be seen in the National Science Educations Standards and the National Curriculum. It is also apparent that even with the differences in the content of life science

Table 3: Life processes and living things program of the United Kingdom's (England and Wales) National Curriculum.

	Key Stage 1 (5-7)	Key Stage 2 (7-11)	Key stage 3 (11-14)	Key stage 4 (14-16)※
Content	Life processes	Life processes		
			Cells and cell functions	Cell activities
	Humans and other animals	Humans and other animals (Nutrition, circulation, movement, growth and reproduction, health)	Humans as organisms (Nutrition, movement, reproduction, breathing, respiration, health)	Humans as organisms (Nutrition, circulation, breathing, respiration, nervous system, hormones, homeostasis, health)
	Green plants	Green plants (Growth and nutrition, reproduction)	Green plants as organisms (Nutrition and growth, respiration)	Green plants as organisms (Nutrition, hormones, transport and water relations)
	Variation and classification	Variation and classification	Variation, classification and inheritance (Variation, classification, inheritance)	Variation, inheritance and evolution (Variation, inheritance, evolution)
	Living things in their environment	Living things in their environment (Adaptation, feeding relationships, micro-organisms)	Living things in their environment (Adaptation and competition, feeding relationships)	Living things in their environment (Adaptation and competition, energy and nutrient transfer)

Note: Key stage 4 includes single science and double science; a majority of students choose double science.
The table shows the double science program.

Source: Reference [5] and The National Curriculum for England.

education, in both countries emphasis is being placed on understanding life science in a systematic way.

Japan also needs to undertake long-term efforts to increase scientific literacy. The 21st century is the “Century of Life.” Systematic life science centering on molecular biology must be properly positioned in education so that knowledge can be added in developmentally-appropriate stages. This requires an examination of the structure of science education.

1.4 Conclusion

The fostering of researchers is one of the most vital issues ensuring the advancement of life science, which is expected to support Japan's industrial base in the future. Life science education and research of universities must be improved to accomplish this. Furthermore, because life science has become an multidisciplinary field and has come to have an impact on society as a whole, graduate schools must be prepared and curricula developed to teach life science systematically and comprehensively. What type of education system should be developed is a question that will be asked of universities as the national universities become more independent of the central government, and will require government support as well.

Individuals and society will debate and judge issues such as bioethics that arise from life science. Education will play a vital role in raising of society's life science literacy from a long-term perspective. Systematic life science centering on molecular biology must be properly positioned in education so that knowledge can be added in developmentally-appropriate stages. The time has come for an examination of the structure of science education.

Acknowledgements

This report is based on a lecture entitled “The critical situation of life science research and education in Japan’s universities” presented by Professor Mitsuhiro Yanagida, dean of the Kyoto University Graduate School of Biostudies, at the National Institute of Science and Technology Policy on 18 July 2002, with the addition of our own research. We received important suggestions for the advancement of life science in Japan from Professor Yanagida, who is on the front lines as a life scientist and educator. Since we were unable to touch on all of them in this report, we would like to end by presenting a brief summary of them here.

Professor Yanagida graciously provided us with relevant literature as well as offering overall

Appendix.: Professor Mitsuhiro Yanagida's suggestions for advancing life science research

(1) Improving life science education

A. Change in primary and secondary education is required.
- A two pronged-teaching approach through natural history style biology and through life science.
- Early education regarding genes.
- Training of life science educators

B. Establishment of new departments and graduate schools in universities is required for the training of students in life science fields.
- Establish life science departments separate from existing current science, agriculture, pharmaceutical sciences, and medical departments.
- Establish life science research departments in graduate schools.

(2) Training outstanding people

A. A system that maintains continued outstanding research must be built.
- Improve the quality and objectivity of research evaluation.
- Relax retirement age restrictions for outstanding researchers.
- Provide economic support including scholarship systems to help graduate students.

B. Leadership training is needed.
- Young (in their 30s) research leaders.
- National leaders with international status.

C. Necessary elements to train human resources
- An environment that welcomes foreign researchers and foreign research leaders.
- An environment that welcomes female researchers and allows them to become leaders.
- Improved English ability for Japanese researchers.

(3) Conditions and issues in Japan’s life science policy

A. National unique sense of values is necessary for determinining policy.
- Policies should not be determined to oppose to the U.S. and Europe.
- Japan should cooperate with the U.S. and Europe where possible.

B. National policy (funding flow) must be scrutinized.
- Outstanding grant systems should be continued in a good direction.
- Results obtained by the public corporations that carry national policy must be scrutinized.
- Outside evaluation of funding flow as national policy is necessary.

Source: “The critical situation of life science research and education in Japan's universities,” National Institute of Science and Technology Policy Lectures No. 90.

direction for the report. We gratefully offer our thanks to him as well as to Associate Professor Tetsuo Isozaki of the Hiroshima University Graduate School of Education and Associate Professor Yoshisuke Kumano of the Shizuoka University Faculty of Education for providing us with various types of information.

References

[1] Council for Science and Technology Policy (21st meeting), “About the challenge for science and technology-related budgeting in the FY 2003.” (http://www8.cao.go.jp/cstp/siryo/haihu21/siryo1-1.pdf)

[2] Namio Nagasu, ed. Translation by Yoshisuke Kumano, Testuro Tanzawa, et al. “National Science Education Standards:The future of the USA science education is viewed.” Azusa Publishing, 2001.

[3] Yoshisuke Kumano,“USA:Trend of the science education reform and directivity of the new science education course.” (National Institute for Educational Policy Research,“Research on curriculum improvement of the science subjects: the trend of foreign countries,” pp. 83-102, 2001).

[4] Tetsuo Isozaki,“National Curriculum.” (Society of Japan Science Teaching, “Future science education investigated from the keyword,” pp. 32-37,Toyokan Publishing, 1998).

[5] Tetsuo Isozaki,“United Kingdom:With the aim of the new science education.” National Institute for Educational Policy Research, “Research on curriculum improvement of the science subjects: the trend of foreign countries,” pp. 1-35, 2001).

[6] Mitsuhiro Yanagida, Science of “Life” : Life science is very interesting, Nihon Keizai Shinbun, 2001.

(Original Japanese version: published in October 2002)