

Brain Science *lato sensu*

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1 Introduction

Today, the implication of the term *brain* is expanding. For conditions endogenous to neuroscience/psychiatry/neurology, it is clearly impossible to describe the development and functions of the brain or states of mind only in terms of the brain as an organ. Research now underway is based on interactions between brain and body, self and others, and human beings and society/environment. Since the latter half of the 1940s, various methodologies and bodies of knowledge have been combined and integrated to create an academic field that can be called "Brain Science *lato sensu*" (hereinafter, "Brain Science"). This area is still expanding.

Meanwhile, exogenous factors are also raising social expectations for Brain Science. First, in 1963, UMESAO Tadao recognized the arrival of the Information Industry Age, which he also called "cerebral/sensory industry".^[1] He advocated the importance of not only information that works upon the intellect but also of sensory information, which works upon the senses, and of experiential information, which comprehensively stimulates the five senses. In recent years, the importance of sensory and experiential information has been increasing. UMESAO also predicted that the spiritual industry would succeed the information industry. As society realizes the limits of its reliance solely on growth through the industrialization of materials and energy, it has become necessary to shift to the pursuit of sustainable maturity through the spiritual industry.

In 1969, TODA Masanao^[2] predicted that an aging society could not assimilate accelerating changes and excess information, and that dissatisfaction would grow along with affluence.

The urgent task of humanity is therefore to

create a society where each affluent individual can directly participate in cycles of information-acquisition and their feed-forward control (i.e., creative processes). Psychology (today's cognitive science), he predicted, would play an important role in achieving this.

Beginning in the 1990s, people became aware of the weakening of common values, information overflow, and opacity in society. After 2000, Japanese people have come to long for the following in the coming decades: the healthy growth of their children, lifelong opportunity of learning, tolerance and diversity in society, a society that pursues spiritual affluence, state of 自足 (humble satisfaction with life), autonomy and satisfiable quality of life for the elderly and disabled, and a safe and secure society.^[3] Supporting people through the development of Brain Science is an important issue for government in order to respond to these desires.^[4]

The brain is an interface where the tangible level of the physical body encounters intangible levels such as information, meaning, spirit, and mind. Brain Science is an important venue for discussing the intersection between empirical natural science and academic fields that address the emergence of meaning. From the perspective of changes in science, technology, policy, and society, this report will discuss the process by which "Brain Science *lato sensu*" was formed and the themes that "Brain Science" should henceforth address.

2 Research areas comprising Brain Science

Until the first half of the 20th century, studies of the mind, nervous system, and 心 (kokoro) in natural science were performed independently in disciplines such as psychiatry, anatomy,

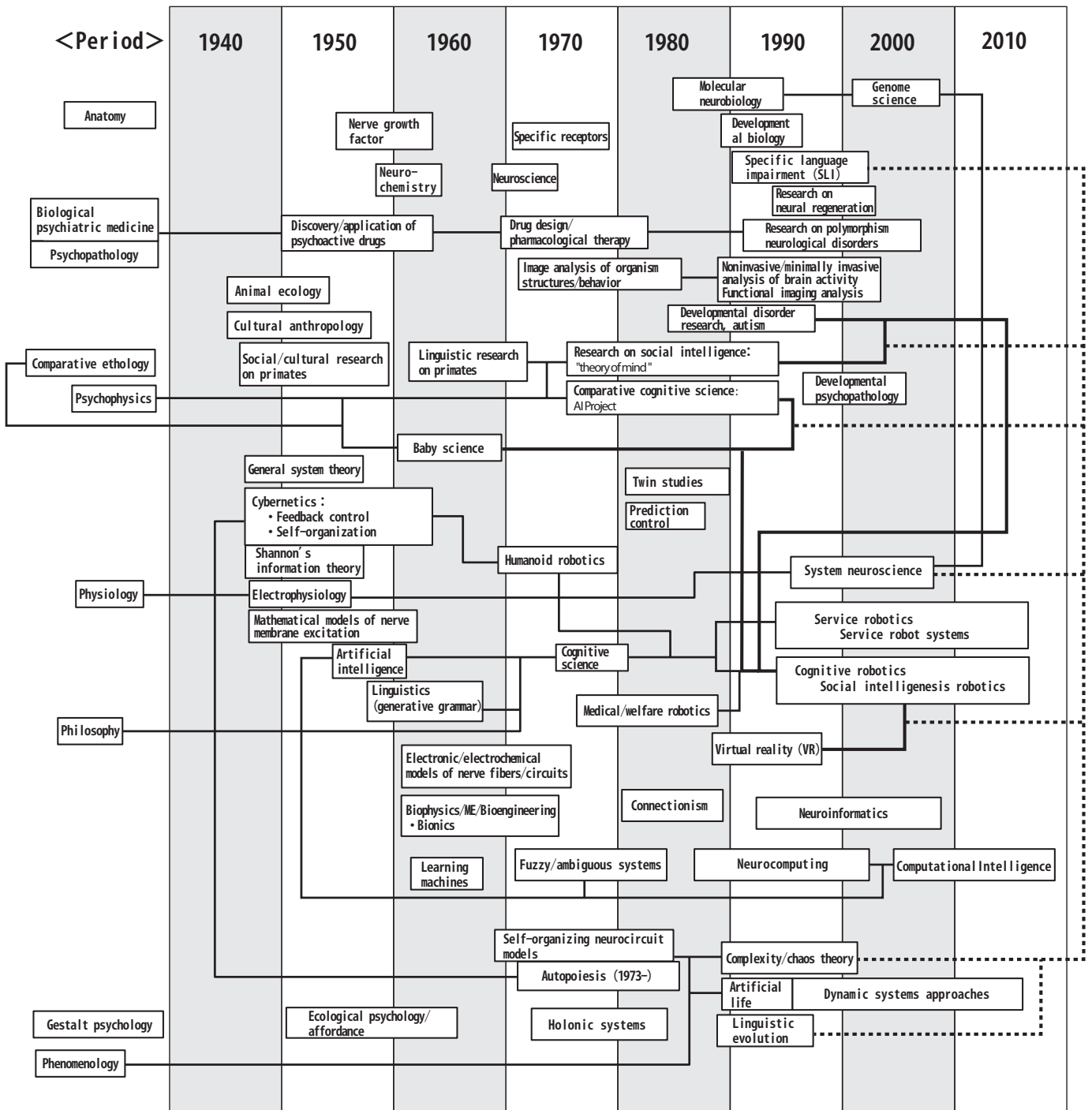


Figure 1 :The formation of Brain Science

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Figure 1 depicts an overview of the flow of association and integration of various types of research related to today's Brain Science. The left end of each box approximately indicates the dates of initial announcements of the theory or formation of schools described in the box. From the top, Figure 1 generally classifies research categories: 1. molecular biology and genetic analyses, 2. studies on human and monkey individuals and groups, 3. engineering & computational neuroscience such as robotics (mainly approaches based on internal models), and 4. research based on nonlinear dynamics, complexity, and chaos. Comparative studies on the development and its perturbation of humans, monkeys, and robots in communities and societies thereto are being carried out beyond the general categories and generating significant knowledge (bold lines). Research in areas that use nonlinear dynamics will become increasingly important for analyzing individuals with different personalities and characters and mental states fluctuating in real life. The dotted lines indicate association and integration expected in the future. Association and integration of psychopathology and behavioral genetics with twin studies, long-term longitudinal research, and virtual reality (VR) are expected. Their connection is not indicated in Figure 1 because of complexity. Today, the birth of cognitive science is often attributed to a series of conferences and articles in 1956, but the date it was established as academic communities (societies) is indicated here in the 1970s^[5]. Although some studies, twin studies for example, have a long history, the time when methodologies similar to those used today were established is shown.

physiology, and psychology. After World War II, concepts, theories, and researchers from fields of physics, engineering, and information science, such as cybernetics, have been introduced in this research. Furthermore, methods and concepts from biochemistry, pharmacology, molecular biology, developmental biology, and genetics were successively introduced, and many researchers from those fields joined in the work. Meanwhile, fields such as computer science, linguistics, psychology, and philosophy formed cognitive science, and the boundaries between it and brain/neuroscience have been falling in recent years^[5]. There have been methodological advances in fields such as psychophysics, measurement and visualization of brain activities, and cognitive psychology. Research on the functioning of healthy intact individual humans and other primates is also progressing. (See Figure 1.)

The accumulation of diverse knowledge and methodologies and the ability to process vast amounts of information at high speed with computers, along with collaboration among researchers with varying perspectives, have led to results such as the following.

- 1) Systemic scientific analysis connecting different levels such as molecules, cells, modules, functional areas, and the central and peripheral nervous systems has become more important.
- 2) Simulations from appropriately macro

perspectives to understand mental phenomena without reference to micro-levels (creation of intelligent life/constructive approaches) have flourished. Broadly speaking, there are two motivations.

- Researchers discovered that characteristics of entire systems could not be defined due to the nonlinearity and complexity of the brain, even when lower-level information such as molecules and neurons was integrated.
 - In pedagogic, medical (such as psychiatry) and vocational venues, holistic rather than reductionist descriptions are desirable.
- 3) More researchers began to tackle themes such as gestalt perception, linguistic and cognitive evolution, decision-making and free will, consciousness and unconsciousness, and the construction of self, which were previously difficult to study empirically. Hypotheses and ideas that had not been investigated by the majority of researchers because they were considered too avant-garde, abstruse, or premature (e.g., G. B. Vico, C. S. Peirce, G. Bateson, the origin of language, B. Libet) are therefore being reevaluated. This is creating environments that promote empirical research.

Among the above changes, some newly discovered knowledge relevant to Brain Science and some new issues garnering attention include

the following.

1) Awareness of self and others

In addition to clinical research on disease and injury cases, psychophysics studies on healthy humans have found that awareness of self and differentiation between self and others are variable. Awareness of the self is continually constructed through the interaction of perception and behavior.^[6-7]

2) Understanding of the behavior and intentions of others

Mirror neurons, which were discovered through electrophysiological research on monkeys, contribute to interactions between self and others in terms of understanding the behavior of others, constructing self-body-image according to that, and actual imitation/emulation. Psychology experiments using noninvasive measurement of brain activity in humans have found similar phenomena, suggesting the existence of a mirror neuron system for the imitation of others and the understanding of their intentions.^[8]

3) Free will and decision-making

Recognition that one makes intentional judgments and choices may be an ex post facto explanation for phenomena that occur in the brain and body. For example, the existence of readiness potential, which occurs in the brain some hundreds of milliseconds ahead the intention to act, is well-known.^[9-10]

It is understood that there are two types of decision-making systems, a system for making statistical judgments and a system for making judgments based on individual history and present circumstances.^[11] Reproducibility has been fundamental to empirical research since Bacon, yet these studies support the phenomena that human beings can obtain firm ideas in just one moment.

4) Backward Referral and Prospective Control

Time perceived by human being's first-person sense actually have a certain range from the moment called "now" to the past just before "now" and the projected future immediately after. Behavior is inevitably accompanied by prospective

control such that humans may ignore the difference between prospect and reality as far as it is within allowable limits. This suggests normal prospective control may share basic mechanisms with the sense many people with schizophrenia have that "their minds are read and seen through by others," "their actions have already gotten ahead," and "they are conducted to" act.^[12-13]

5) The bases of forming social relationships

During infancy humans develop a "theory of mind" to estimate and understand the intentions and feelings of others. Studies on people with autism who have certain difficulties in this development, accelerated analysis of bases for forming social relationships with others from the viewpoints of Brain-Science.

6) The roles of affect/emotion

Neural mechanisms^[14] and cognitive functions of emotion/affect, the physiological significance of psychological stress, and the role of emotion/affect in decision-making.^[15] Biological research on psychological stress has been carried out from the perspective of basic biological reactions (stress reaction) by living subjects to maintain homeostasis in the face of external stimuli.

In addition, the following are also examples of areas where technological development has occurred within Brain Science.

- 1) The proliferation of noninvasive measurements of brain activities has lessened the distance between brain/neuroscience, which studies the brain as object, and cognition science, which studies information processing processes within the brain.
- 2) The discovery of neural stem cells in the brains of adults has increased the possibility of clarifying structural changes in individual brains according to personal cognitive history.

Ongoing and new research themes for Brain Science that deserve promotion include the following.

- 1) Elucidation of mechanisms for constructing the self and its quasi-continuous awareness based upon relationships with other conspecifics;
- 2) Elucidation of the phenomena of individuals with different personalities and characters, not just

- of universal human characteristics;
- 3) Elucidation of the process by which various cognition and behaviors are generated or halted, in addition to descriptions of states when a certain response to a specific test is stably taking place;
 - 4) Elucidation of the emergence of a subjects' actual feelings and meaning based on her/his propensity, memories, and experiences and of the ways meaning is generated, rather than descriptions of phenomena described from outside;
 - 5) Research that proceeds from the prospective of linking Brain Science to the elucidation of life itself and of mechanisms for maintaining ecosystems.

3 | The forming of Brain Science

This report discusses how disciplines were combined and integrated to form Brain Science, what can be understood from this process, and potential developments in Brain Science.

3-1 *Brain Science in primates*

Primates in Japan began in about 1948, with research on Japanese macaques based on animal ecology and cultural anthropology. The identification of individual monkeys combined with longitudinal observation was pursued to extract essential factors of society through changes in relationships among individuals.^[16] The creation of cultures such as familial systems or tool uses, their propagation, and changes are analyzed. This comparison with monkeys shed light on the notion that the family system of human is quite unique to human beings. For example, not only children and their mother but also the father and grandparents live together, and furthermore also members of the community provide support from outside the family. In Japan, Japanese macaques are often used in electrophysiological research to study changes in body image and cognitive patterns associated with tool use. Similarities and differences of results obtained for them and for humans are compared.^[7]

Some propose a hypothesis in which the postmenopausal lives of individuals have lengthened in order to "create grandmas" as a childrearing strategy in humans. In anthropology as well, an important concept is the idea of tense relationships ("avoidance relationships") between close generations such as parents and children

and "joking relationships" between more distant generations such as grandparents and grandchildren that allow teasing or frank talk about topics usually considered socially inappropriate. This is believed to exist even today in many societies, including some Asian ones. In Germany, researchers are conducting a study based on the perspective that living with younger people benefits in turn the health of elderly people.

Research on the minds of chimpanzees, which began in the occident early in the 20th century, has progressed in two directions following the language research of the 1960s–1980s, i.e., research on social intelligence and on comparative cognitive science. In social intelligence research, "theory of mind" is a major theme. As in research on human developmental psychology and autism, studies of empathy, social reference, imitation/emulation, and joint attention are underway.

Meanwhile, comparative cognitive science such as Japan's AI Project applies psychophysics methodology to the scaling of sense and perception in order to measure color sense, visual acuity, number concepts, and memory capacity. While psychophysics has been used to study mainly adult humans since the 19th century, in recent years it is often used in studies of babies, who are hardly instructed or trained verbally, or unable to respond verbally. The same scales can be used to analyze functions of robots too. This enables comparisons of the cognitive functions of humans, chimpanzees, and robots.

Research is underway in cognitive archeology on analysis of changes in human cognitive patterns accompanying evolution, changes in living environments and social structures. Other research is focusing on analysis of the genomes of modern humans, Neanderthals, and other primates, and on the comparative development and behavior of human beings and other primates. The ensemble of these studies will enable understanding of interaction between cognitive change of humans, creation/use/improvement of tools, and exploitation/reformation of environments.^[17]

With a notion that it is no longer the time to focus only on primates and it is essential to promote research on entire ecosystems, Kyoto University is reforming its Primate Research Institute and its outdoor observation facilities based on this

idea. In the USA, large primate research is a key notion of the movement advocating a "Decade of the Mind" initiative following the "Decade of the Brain" (1990–2000) and "Decade of Pain" (2001–2010) initiatives^[18] and of CARTA, the Center for Academic Research and Training in Anthropogeny ("anthropo" + "geny"), which aims at elucidating human diseases from an evolutionary point of view and was launched in FY2008 based at the University of California at San Diego (UCSD) and the Salk Institute including an internet-based virtual research center.^[19]

3-2 *Physics/engineering/information science/mathematics theory*

Based upon the progress of electrophysiology since the end of the 1940s, followed by the spread of cybernetics, research on biological information processing inspired by Shannon's information theory, and the improvement of electronics, which enabled detecting weak biosignals, and processing and calculation of large data, bionics emerged during the 1960s combining biology, physics, engineering, and mathematical science. Because the characteristics of neural systems as control machinery and the morphology, electrochemical characteristics, and networking of neurons were attractive for engineers, vigorous modeling and empirical testing have begun. Through medico-engineering collaboration, research on artificial neuron/organs, remote detection of in vivo information, and learning/memory of machines has started.^[20]

In the 1970s, research on humanoid robots with a computer as the brain and mechanical actuators as the body began. As demand for rehabilitation increased, and Japan's aging society arose as a social issue in the mid-1970s, Japanese researchers quickly launched research on medical and welfare robotics, including prosthetic/nursing equipment and "guide dog" robots.^[21–22] These approaches have developed into research on service robotics, service robot systems, and virtual reality (VR) today.

The 1990s saw the beginning of robotics research to study human cognitive functions and bases of development and social intelligence through constructivist approaches that create functional systems and verify cognitive and behavioral

models within the systems.^[23] This is an important methodology for the elucidation of the mechanisms of human problem-solving and communication in a complicated and unpredictable real world.^[24] In the past, robots were considered just objects to be manufactured and used in closed environments such as laboratories and factories. Japanese robotics researchers and companies in the 1990s came up with the innovative concept of conducting research and development of robots, which were projected for direct contact with the general public in their daily life.

As research and production facilities, transportation, information, and decision-making systems grow larger and more complex, it has become clear that even with the advancement of mechanical control systems, risk of disasters cannot be eliminated because of human factors such as neglecting, ignoring, or mixing up procedures through inattention, misunderstanding, fatigue, or over-habituation. Thus, human-machine interfaces are being improved and VR-based training systems are being developed based on understanding human cognition and behaviors.

3-3 *Nonlinear dynamics, self-organization, and complex systems*

A concept of 'self-organization' was discussed in Wiener's "Cybernetics" besides 'feedback control.' In 1954, KUBO Ryogo (University of Tokyo) and TOMITA Kazuhisa (Kyoto University), et al., pioneered nonlinear physics, and they have been followed by a number of leading researchers. In recent years, research on artificial life has also flourished in this context.

In the early 1960s, NAGUMO, an expert on nonlinear oscillators, created an electronic-circuit model of nerve fibers using a tunnel diode based on the Hodgkin-Huxley's mathematical model of the excitation of the neuronal membrane. He also created an electrochemical model of the reverberation of excitation patterns. These models became one of cues for following bionics research in Japan.

In 1973, neurophysiologists MATURANA and VARELA conceived the idea of autopoiesis^[25]. This theory describes life from an internal perspective rather than that of an external observer. Although the theory has yet to prove anything, it has been

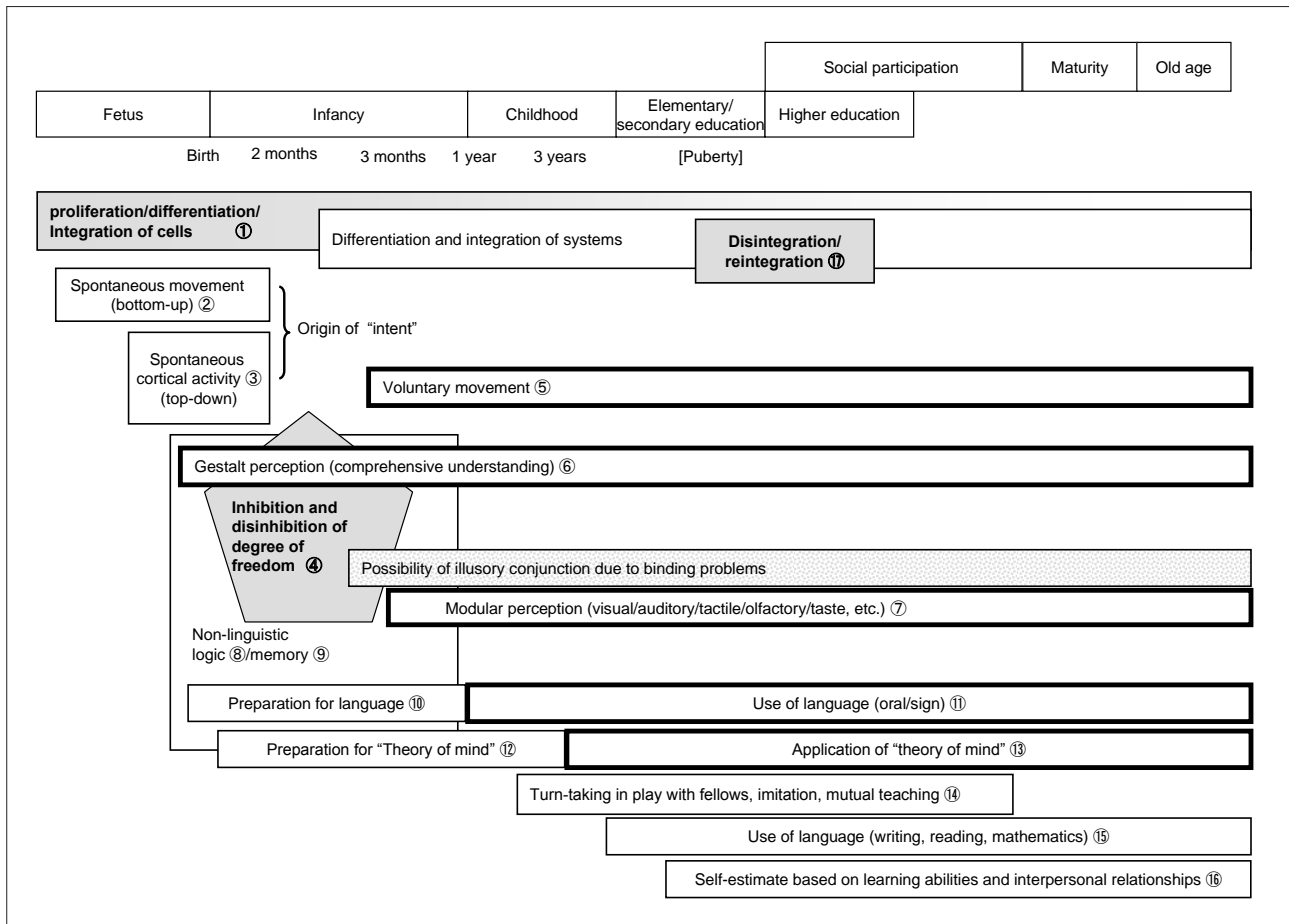


Figure 2 :Differentiation and unification of nerve/body system in life

Prepared by the STFC based on References^[29-31]

The multiple factors associated with difficulties, disabilities, or diseases that may (or may not) manifest with growth may have their synchronously roots or tend to interact among them in certain stages of development. Long-term and longitudinal perspectives must be taken based on entire human life history while making good attention on turning points of growth from scientific viewpoints.

incorporated into concepts in artificial life, robotics, and virtual reality for education and medical treatment.^[26-27] It is expected to obtain proofs through simulations and real-world verifications in these fields. As the concept is relatively plausible in the description of the neuronal system, expectations are high that novel ways of understanding life may emerge and be propagated from understanding the brain and cognitive functions with the theory.

In Japan in 1978, SHIMIZU Hiroshi advocated holonic systems.^[28] In 1986, regarding models of cerebral visual pattern cognition he proposed that the interpretation of meaning emerges through the interaction of top-down and bottom-up signals and the information self-organizes in the brain. In 1990, TSUDA Ichiro reported a chaotic itinerancy phenomenon in neuronal circuit models. This has garnered attention in relation to dynamic

associative memory in the brain.^[29]

Nonlinear dynamics is applied for the elucidation of developmental process of fetuses and infants in recent years. (See Figure 2 for {1-17})

Simulations are being conducted on the processes through which the immature nervous systems of fetuses cause physical movements, find various patterns of spontaneous movements, and based on such repetition, the cerebral cortex comes to self-organize while reflecting physical structure (3).^[31] The hypothesis that during a newborn's U-shaped development, after decreased freedom at about 2-3 months (4), gestalt perception (6) shifts to modular perception (7) controlled by intention in the cerebral cortex^[29] is being investigated. The development of foundational ability in the preparatory stage (10-12) for voluntary use of language (11) and application of "theory of mind"

(13) is also being analyzed.

The following are some themes that should be promoted in the framework of Brain Science.

- a) Nerve precursor cells undergo active division and proliferation in fetuses. Precursor cells, which have had some degree of freedom, differentiate during this process into neurons with various degrees of freedom. The mechanism by which robustness of the entire system is generated through the interaction of neurons that have differentiated from similar precursors can be studied (1).^[29]
- b) The hypothesis that voluntary movement (5) is generated when the freedom of spontaneous movement originating from the subcortical neural activities (2) is once suppressed by spontaneous activities of the cerebral cortex (3) is momentarily inhibited and then released.
- c) The risk of imperfection in selective attention and illusory conjunction during the shift from neonatal gestalt perception (6) to the additional state with modular perception (7), and its presumable relationship with future synesthesia and dyslexia (15). The relationship between gestalt perception and synesthesia.
- d) The relationship between nonlinguistic intellect and linguistic- and social intellect.
 - Elucidation of logical deduction in infants before they use language (8) and elucidation of the mechanism for generation of stimulus equivalence which is illogical but characteristic of human beings and contributes to higher-order cognition such as symbol use (15).
 - Development of nonlinguistic memory (9). The relationship between gestalt perception and synesthesia (c) with the "grounding of

Why are non-linear dynamic approaches necessary?

Because human neuropsychiatric systems have the characteristics described below, analysis using nonlinear dynamics is advantageous.

The brain is nonlinear: The brain is a nonlinear system and it is impossible to determine its characteristics by adding up information in sub-layers such as molecules and cells. Reductionist approaches such as molecular biology that separate the system into (material) parts for study therefore cannot address some aspects of the brain. Furthermore, due to non-linearity in the generation of perception and behavior models, learning may not be achieved successfully only by imitation of others using the forward-reverse relationships of the models.

Generation of movement and perception: In most simulations of human behavior using robots to date, robots lack autonomy or motives. Generally, engineering and computational approaches take the existence of goals for granted, and researchers externally set goals for robots (for example, imitating human movements). It is therefore often impossible to study the mechanisms by which movement and perception emerge. Assuming control solely for purposefulness, improper configuration due to excessive freedom becomes the problem. Restrictive conditions must then be introduced to avoid this situation.

People often act non-purposefully: Most human behavior is not purposeful. A certain part of it is, at the same time, purposeful and it is difficult to distinguish. Goals, attention, and interest shift during the processes of action and perception. Subjects and rules change during conversation and games. Natural human activities rise, go on and cease including these fluctuations and flows.

Generation of meaning: Information that enters bottom-up from a sensory organ is polysemous, and top-down mechanisms act on it to attribute certain meaning to the information. Moreover, human brains demolish perceptions of a meaning after they have been fixed, replacing them with other sets of perceptions with deferent meanings (e.g., switching the figure and ground of a visual stimulus). Human beings thus do not objectively recognize events or objects existing outside of themselves as they really are, but instead segment and interpret them (to create meaning).

Temporal development: A human being's subjective sense of time comprises the moment called "now" in series with the past and the near future. The flow of time is supported by embodiment, morphology, experience, memory, and so on.

References^[28-30]

memory."

- The mechanism that the entrainment into languages games takes place based on premature linguistic (10) and social (12) abilities and that it shifts to voluntary speech (11).
- e) • The mechanism by which infants shift from understanding the "theory of mind" of others to understanding a "theory of mind" for themselves (13).
- Turn-taking of roles and rules during play, imitation, and reciprocal teaching among fellow infants (14).
- f) • The mechanisms by which meta-cognition about one's own ability develops at the age of approximately 9 or 10, and self-esteem develops due to complex factors including the meta-cognition and social interactions with others. In addition, the mechanism by which difficulties with reading and writing may hinder this development.
- The mechanisms by which the abovementioned systems disintegrate and reintegrate along with drastic physical changes including the nervous system during adolescence (17).

Furthermore, in order to study correlations among these various phenomena and their relationships to latent difficulties, disorders, and diseases that often manifest only after a certain interval, it is necessary to outline a long-term project of longitudinal research from an early stage and to promote various research under the context of this project. Additionally, comparison with primatological research on the development of young chimpanzees and monkeys would also be effective.

Following the dynamic systems approach advocated by Thelen, et al., in 1994, in fields of developmental research and developmental psychology, the analysis of macro phenomena are being carried out inspired by concepts of nonlinear dynamics and using them in the figurative sense. It would be useful to watch the future progress of such analyses and to take up phenomena that can be subjected to strict analysis using genuine nonlinear dynamics and to design appropriate research projects.

3-4 *Brain Science linked from molecular aspect*

Various neurotransmitters were identified in the 20th century. An academic society for neurochemistry was founded in 1958 to seek out molecular changes as the causes of mental illnesses that take place without any obvious changes in macro morphology. Around 1970, an academic society for neuroscience was founded. Psychotropic drugs were discovered in 1952, and their clinical application began, contributing to the progress of neuropharmacology. During the 1970s, endogenous opiate receptors were identified, drug design became full-fledged, and pharmacological treatment of mental illness expanded. Analysis of interactions among neural substances began through the adoption of molecular biology methods during the 1980s. Starting in the 1990s, system scientific approaches became active where research at the molecular level, physiology and information science are integrated.

Furthermore, introduction of methodologies and personnel from developmental biology led to analysis of the structures and functions of the neuronal system from viewpoints of ontogeny and phylogeny. In clinical medicine, although it was already known that development of intelligence, linguistic ability, social interaction, and conduct abilities can be perturbed by neurological factors, developmental studies on cognito-psychological functions and brain activities began in addition to the traditional studies depending solely on brain autopsies. Research on autism and specific language impairment (SLI) has not only contributed significantly to understanding higher-order functions in humans, but also provided useful conceptual frameworks for robotics. An example of progress for such research is the understanding that underdeveloped abilities can be improved with training. In recent years, this has been discussed also in the general framework of school education.^[32]

Positional cloning has identified genes related to psycho-neuronal disease. Genes related to specific language impairment have been identified through familial studies of high incidence. Phylogenetic analysis of such genes inspired research on cognitive evolution and language evolution.

Furthermore, simulation of the action of classical

neurotransmitters and the neural networks conveying them is being used to study behaviors such as expectation, exploration, and learning in cyber-rodents. This research connects molecular science, engineering, and behavioral science.^[33]

4 Brain Science in Japanese science and technology policy

In Japanese science and technology policy amidst the social changes from the post–World War II reconstruction, the rapid economic growth to the present age of diversifying values, Brain Science has been promoted as an important research area in order to prepare for predicted future social circumstances and to meet social needs.

In recent years, increasing numbers of cases are seen where conditions in the real world largely affect the directions of research projects, or scientific knowledge and technologies come to their maturity only being practically applied in society. This has narrowed the gap between research and the real world. Brain Science is no exception.^[34]

During the 1990s, as ministries and government offices began to boost research from various interests in brain science, the timetable for strategic goals based on ‘the long-term perspective on brain science research and development’ was settled. An overview of policy trends that have affected Brain Science is described below.

4-1 *Changes in welfare, healthcare, labor, and transportation, and the development of Brain Science*

After World War II, relative morbidity of mental disorders and cerebrovascular diseases began to increase, as that of tuberculosis decreased. In 1955, brain research was pointed out as one of the basic research areas that should be extensively promoted in Japan.

During the 1960s, the threat to health from mental tension, fatigue, maladaptation, and stress associated with rapid social changes and increasing complexity was pointed out.^[35] Optimistic expectations on human engineering to provide countermeasures took place at first. Advances in psychiatry and the development of psychotropic drugs raised expectations for the returning of patients to society, and study of home- and

community-based mental health care began.

During the years 1970–1975, the morbidity of elderly people raised sharply, with the peak age group rising to age 75–79. After the population of people who would have certain difficulties in living a normal life in 2020, i.e., those who would be elderly, disabled, or caring for them, was estimated, development of welfare equipment was promoted as a means to cope with the advent of the aging society.^[36] Furthermore, the past trust in human engineering, in which conditions of patients were simply considered as matter of engineering specifications turned out inadequate. New ideas in engineering able to meet individual needs were sought in order that it can meet requirements of individual humans.^[21] There was a change in the way the health of elderly people is viewed as well. Elderly people suffering from dementia came to be treated as suffering from mental disorders rather than simply being dismissed as "senile".^[37]

Since the second half of the 1970s, demand for medical rehabilitation has climbed rapidly as workplace and traffic accidents have increased, and the number of people suffering strokes and their aftereffects has risen. The increasing incidence has led to the progress of clinical research on sensorimotor and linguistic functions. In addition, through medico-engineering collaboration, the development of computerized prosthetics, nursing equipment, welfare robots ("guide dog" robots, etc.) and artificial neurons and the preparation of enclosing environments that enable the most effective use of these devices are being promoted.^[20, 22]

During the 1990s, increases in depression, death from overwork, and suicide were raised within the focus of public attention. Entering the 2000s, consideration of ‘countermeasures against depression as a means to prevent suicide’ began. Furthermore, examination in the context of Brain Science of various previously overlooked issues such as those below also began.

- Human factors such as inattention, mistakes, and negligence that cause serious disasters, for example, in aviation and nuclear power plants.
- Measures to support decision-making of responsible persons, rescue staff, and the general public in the event of earthquakes and

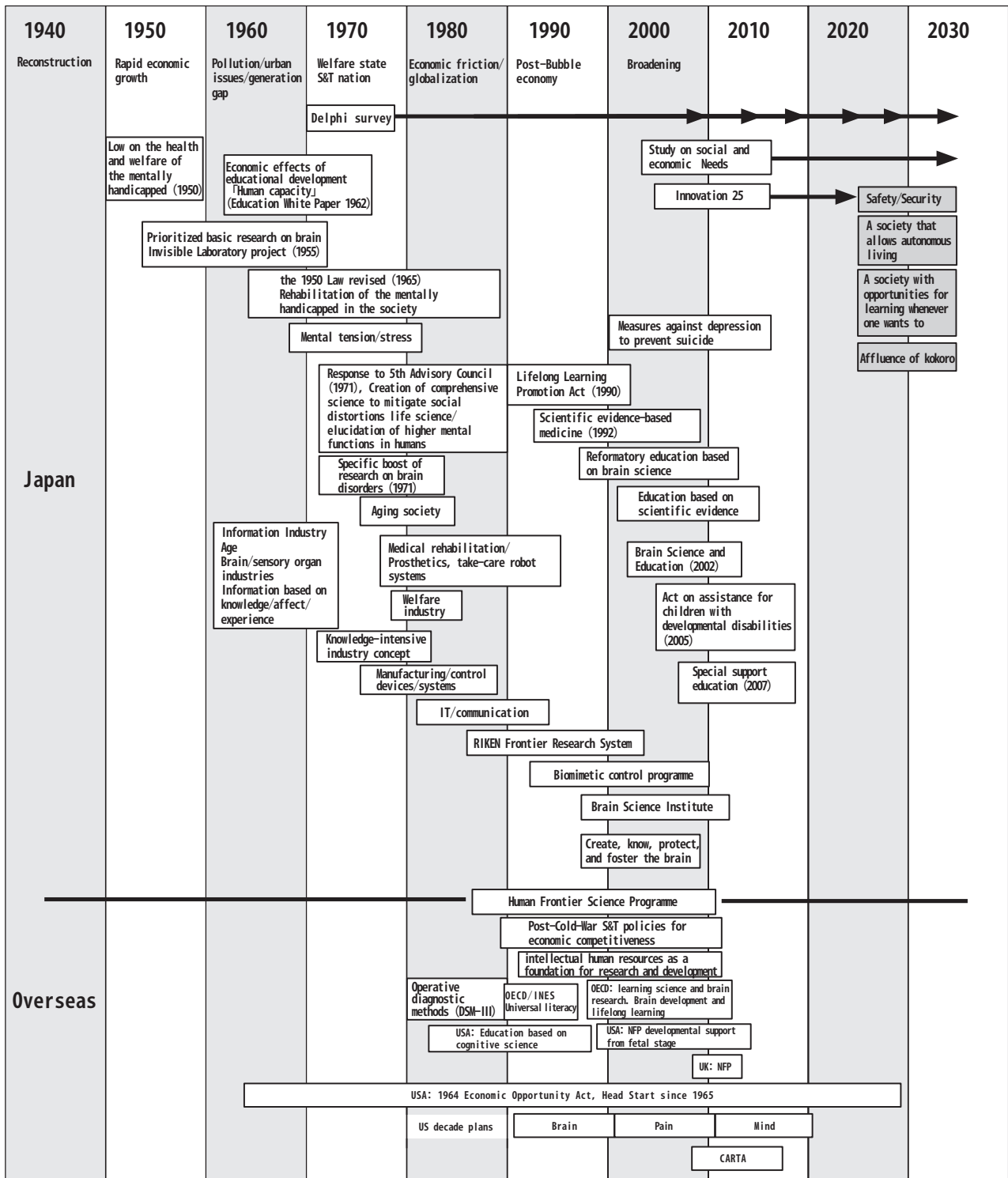


Figure 3 : Postwar policies that influenced today's Brain Science

Prepared by the STFC

Figure 3 depicts the main flow of postwar policies that influenced today's Brain Science. Positions at the left of each box indicate the dates each policy or report was issued. Policies of international organizations and foreign countries are shown in the lower part of the figure.

Characteristics of Japanese policies include the performance of long-term foresight research and the setting of policy goals at an early stage, the continuity of these practices, and efforts to create organic links across disciplines and establish comprehensive science. There are structures that can implement such policies even throughout changes of cabinets. Furthermore, Japan launched an administrative reform to integrate science and technology administration with that for education, culture, and sports ahead of other countries.

other large-scale disasters.

- Effective protocols for effective communication with people with cognitive, perceptual, and/or motor disabilities.

4-2 *Brain Science as a contributor to the elimination of social distortions*

During the 1960s, various social problems such as pollution, undesired effects of urbanization, the generation gap, and the hollowing out of local communities came to the fore. In its fifth advisory report, "On the Basics of Comprehensive Science and Technology Policy in the 1970s"^[38], the Council for Science and Technology Policy asserted that existing science and technologies were inadequate in some ways to eliminate "social distortions." It proposed the creation of a new comprehensive science to solve those issues. Life science, soft science, and environmental science were mentioned as key fields, with support for the humanities and social sciences as well. Items relevant to today's Brain Science were as follows.

Life science

"Information transmission," "memory and learning," "interaction between life and environment," fundamental elucidation of life itself, etc.

Soft science

"Prediction of occurrence of foreseen problems," "consistent and comprehensive planning by systemic elucidation of multiple problems connected deep interrelationships," "improving intellectual potential for creation, judgment, and management in various types of decision-making and research," "science and technology related to behavioral science, social ecology, creation, judgment, cognition, and other intellectual activities," etc.

4-3 *The policy to "create the brain"*

Creation of systems with functions comparable to life system was proposed as a new approach to biological research in 1960. It was already pointed out that creation of an artificial brain alone is insufficient because an artificial brain would not demonstrate the functions of an entire human being.^[39] During the 1980s, some researchers independently began creating intelligent systems

or artificial life in a constructivist way. In Japan during the 1990s, numerous researchers from different fields began collaborating for projects with constructivist approaches to create intelligent systems that have bodies and interact with others.^[23] In 1997, principles for the promotion of Japanese brain science advocated the concept "create the brain" as well as "understand the brain" and "protect the brain." Elucidating brain functions by creating not just the brain, but also bodies that can implement autonomous movement (robot helicopters, etc.) was an attempt to introduce a constructivist approach in science and technology policy.

The following are part of the characteristics of the "create the brain" concept.

- 1) Understanding of the brain as nonlinear systems, which are difficult to elucidate with analytic methods. This is an approach to discovering what is sufficient condition to realize equivalent functions as the human brain does, which differs from supposing the necessity of limited components of the brain by destroying or suppressing them.
- 2) Scientific research on the mechanisms that confer meanings to incoming information and create new meaningful information
- 3) Availability of descriptions arising from an interior viewpoint of the self rather than those from exterior observers
- 4) Possibility of validation in real-world: Research to understand intelligence in the complex and unpredictable real world, with simultaneous advancement of research and development that evolves in the real world and has a high likelihood of application there.

The true value of the "create the brains" research can hardly be predicted from the extrapolation of present situations and may only be widely appreciated after several decades or a century. One of the current problems is the fact that appropriate ways for evaluating and promoting the analytic and descriptive research may not necessarily be the best way for constructivist research. Furthermore, certain issues might only be understood by combining the results of both kinds of approaches. It is therefore necessary to recognize the characteristics of each of them and efficiently carry out science and technology policy.

Asking questions such as "Is it possible to create the brain?" and "Why?" or "Why not?" might be good cues to initiate and promote public dialogue.

4-4 *Japan's education accentuating* 心ころ (*kokoro*)

In traditional Japanese education, character-building has been an important object. From the late Edo period, the percentage of children attending clan and private schools has been high, and each child was educated according to her/his potential. By using calligraphy as core of the pedagogic strategy "learning by practice and reading," the integration of the perception, action, conduct and social skills was fostered.^[40] The percentage of school attendance was maximized by a compulsory education policy since the Meiji period.^[41] A white paper in 1962 reported that the tradition of high school attendance and literacy as one of the foundations for Japan's high economic growth.^[42] Even then and after, the idea that the object of education is "character-building" remains accepted widely.

As Brain Science progresses, the brain's diversity draws people's attention in recent years, and education policies put increasing emphasis on attempts to respond to the individual needs of each infant, pupil, or student to learn.^[43] Regarding the Special Support Education launched in April 2007, the government stated that "Special Support Education is crucially important not only for the education of pupils/students with disabilities but for building up of symbiotic society where, recognizing the diversity of individuals, everyone can enjoy their activities regardless of difficulties, disability, disorder, or any other differences. This initiative is very meaningful for Japanese society, both today and in the future".^[44]

Since the latter half of the 1990s, within the framework of improving reformatory education, Brain Science, such as cognitive science, behavioral science, psychiatry, and developmental psychopathology, has been applied as the base for education and such attempts have been evaluated in actual practices at part of the juvenile correctional institutions under the jurisdiction of the Ministry of Justice. Taking into account minor developmental disabilities, this correctional education is based on lifestyle models that include careful learning plans, dietary therapy and nutrition guidance, physical

discipline, fostering of understanding of others and communication skills, improvement of self-esteem, and training in a disciplined life and group activities.^[45] The understanding and cooperation of guardians are also sought. Fewer youth come again to similar institutes by repeat offense after having finished their terms at institutions where these attempts are being made.

For Special Support Education and reformatory education, the diversity of the brain and the fostering of children's self-esteem are now emphasized more than raising academic ability. Self-esteem of a child or a youth described here is not exaggerated pride, but rather nature cultivated upon an awareness of one's strong and weak points (meta-cognition), the improvement of learning ability based on awareness, mutual understanding with others, and knowledge of how they accept her/himself. People in general, whether they are children or adults, may have difficulties and weaknesses. It is becoming apparent that measures to compensate for such difficulties have not been adequately implemented.

4-5 *Trends in Brain Science in the world*

During economic friction with other industrialized countries in the 1980s, Japan began to globalize its research and development activities. The Human Frontier Science Program launched in 1989 by Japan's initiative promoted international collaboration on brain science from the beginning. In the 1970s in the field of developmental psychology, increasing numbers of observations of babies suggested their richness of abilities immediately after birth. An international survey supported by the Human Frontier Science Program has testified that this is a biological entity that transcends differences in culture or geography.

After the end of the Cold War, many countries reoriented to economic competition based on science and technologies rather than a military one and began turning their attention to mechanisms that the knowledge, on which science and technology stand upon, is created. Furthermore, countries also began considering people involved in research and development or with high skills as resources and began seeking greater efficiency not just in higher education but also in primary or nursery education in order to strengthen the

national level of intelligence and skills. During the 1980s, the OECD began conducting fact-finding surveys and disseminating knowledge regarding universal literacy and "brain science and education."

The USA began the Head Start early education program based on the 1964 Economic Opportunity Act in order to enable children from culturally and economically deprived families to get off to a good start in school.^[46-47] Since the issuing of the 1983 report "A Nation at Risk," the USA has promoted education based on cognitive science.^[5] In the UK, although childhood education was traditionally considered a family matter, since the administrative reforms under Prime Minister Brown, the Department for Children, Schools and Families (DCSF; the equivalent of a new Education Ministry) began addressing childrearing, including childcare and family support. The government supports families and environments for newborns from the prenatal stage. Both the UK and the USA are examining early intervention

to prevent antisocial behavior, delinquency, and crime, tending to consider those phenomena from the perspective of brain/neuroscience and developmental psychopathology.

For promotion of brain science research, the United States Congress passed a resolution setting the policy of the "Decade of the Brain" from 1991 to 2000. In 2000, Congress designated the "Decade of Pain" (2001-2010)^[48], and a possibility of the "Decade of the Mind" as the following decade is now being discussed among academic communities in the main, government agencies and general public.^[18] Concerning pain, high correlation between stimulus and evoked response is seen at the receptor level. Due to cerebral nonlinearity, however, it is not the case in higher order, and the only person who is feeling pain can tell what kind of pain it is, how much it hurts, and how difficult it is to endure. As seen in the theme from "Brain," "Pain" to "Mind," the US Decades are focusing on an increasingly abstract objective. A campaign to define and understand pain is also taking place

Table 1 : Changing approaches in psychiatry

Period	Psychiatry		
1800s	Emotions and understanding directly affected by sensory impressions are etiological locus of mental disorders.		
	Biological psychiatric medicine	Boundary area	Psychopathology
1850s	"Mental illness is cerebral illness" Physical disorders Methodologies of Natural science		Holistic understanding Physical findings alone cannot explain the specificity of experience and behavior, the mind, subject, intuition, self, others, situations
1930s	Shock therapy		
1950s	Pharmacotherapy		Social communication, family therapy of the Palo Alto school (Batson)
1960s			Premorbid personality theory
1980s	Operative diagnostic standards, DSM-III	Twin study epigenetic puzzle	
1990s	Identification of genes related to mental illness Analysis of epigenetic and genetic characteristics		
2000s	Polymorphism Behavioral genetics	"intermediate phenotype"	"Depression-related genes" may be related to the premorbid personality rather than disease itself.

Prepared by the STFC based on References^[51-53]

Even biological psychiatry has begun to consider differences in race and region and to postulate intermediary characteristics for so-called depression related genes, moving closer to psychopathology and the theory of premorbid character. The possibility for cooperative development of biological research, such as behavioral genetics, and psychopathology is increasingly expected.

in Europe through the International Association for the Study of Pain (IASP). In Germany, interdisciplinary research and the establishment of a clinical system are being actively pursued.^[49] In Japan, although outstanding research at the molecular level is underway, there has been no promotion of interdisciplinary research on pain at

the system, cognition, or behavior levels. Little attention has been paid to the "Decade of Pain" movements.^[50]

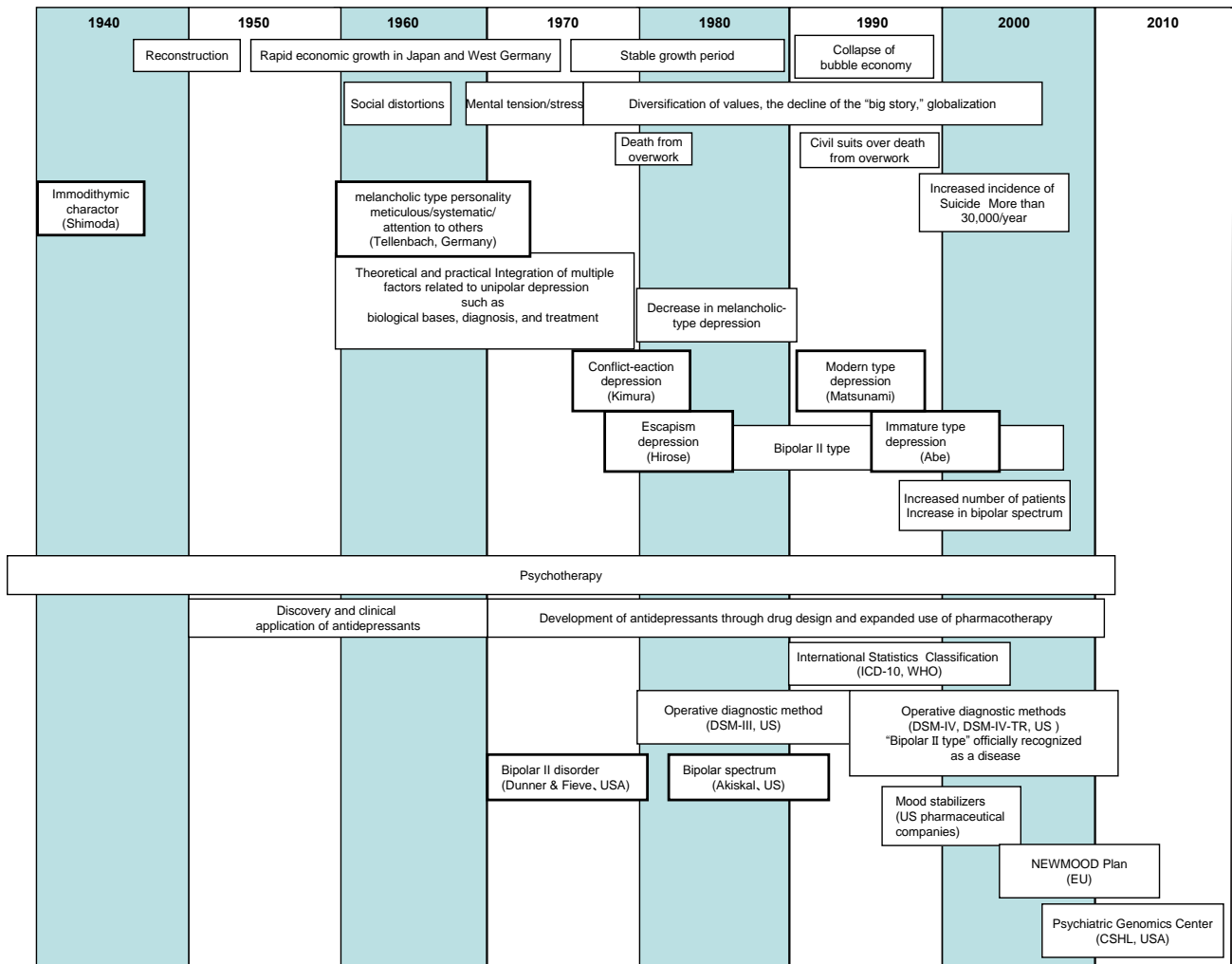


Figure 4 : Changes in mood (affective) disorders

Prepared by the STFC based on Reference^[52]

The broad frames show major types of mood (affective) disorders (depression, bipolar disorder), which vary depending on geography and the times. The left of the box indicates the time when the terms, concepts, or incidence first appeared. In Japan and West Germany during the recovery and rapid economic growth after World War II, the most typical mental illness was the depression seen in melancholic type people who were earnest, had a strong sense of devotion and belonged to organizations, however, they are without a "story after achieving goals." This type of depression tended to decrease with the end of high economic growth. On the other hand, during the era of economic stability and after the bubble economy collapsed, categories of depression diversified, including bipolar disorders with a manic state, and the number of patients increased. The annual incidence of suicides, which correlates with the number of mood (affective) disorder patients, recently kept at the same level of approximately 30,000. From the 1990s, the increasing number of court cases between the bereaved of workers who committed suicide and their companies that were stuck on whether or not overwork caused depression and suicide.

5 | An example of Brain Science promotion: Psychiatry

Psychiatric disorders change along with the times and society. Pathology changes above all. This cannot be explained by the classical genetics, and psychiatric disorders cannot be elucidated with genetic science alone.

Furthermore, what people consider normal or abnormal and how individuals with unusual aspects are accepted or excluded by their families or societies also change along with the times and society. The way others regard and are in contact with patients affects the way they regard themselves and changes their clinical condition. Psychiatry is therefore an area where understanding of interactions among the self, others, the environment, and society manifests as an important element.

Within the psychiatry, psychopathology is a study aimed at understanding the specific nature of a person's experiences and behavior, which can hardly be defined in terms of physiochemical data, and providing treatment accordingly. (See Table 1.) In Japan, a clinical system based on Japanese characteristics and the traditional psychopathology is still practiced, in which doctors and patients develop very careful relationships. It would be important to design research so that it uses a psychopathological framework and utilizes the expertise and tacit knowledge of doctors to link micro-level and macro-level knowledge that would be important.

On the other hand, biological psychiatry has been working to elucidate disorders of the biological brain using natural science methods since Griesinger asserted "Mental illness is cerebral illness" in the mid-19th century. Pharmacological approaches have been increasing their importance since the 1950s. In recent years, vigorous research to identify responsible genes and genetic polymorphism are being made. The Diagnostic and Statistical Manual of Mental Disorders in the USA has employed an operational diagnostic method since the third edition in 1980 (DSM-III). This has advantaged biological psychiatry and psychiatric genomics, promoting biological research and the application of its results. Japan's Health, (Labor)

and Welfare Ministry has used the World Health Organization's ICD-10 in its statistics since 1990. The DSM-III, -IV, and -IV-TR also have a significant impact on clinical practice. (See Figure 4.) Overdependence on operational diagnosis may lead to missing subtle symptoms, jeopardizing trust between doctor and patient, which is indispensable in psychiatry.

5-1 Construction of society with less depression and suicide

The symptoms and frequency of depression are significantly influenced by individual personality and character, physical factors, interaction with others and with society, and the geographical, historical and cultural background of society. In Japan, the number of sufferers and the types of depression and other mood (affective) disorders changed rapidly synchronously with the rapid social changes that followed World War II in addition to social characteristics and personal character traditionally recognized in some people. There is a clear correlation between mood (affective) disorders such as depression and the number of suicides. Annual incidence of suicides has kept at the same level at approximately 30,000 since the end of the 1990s.

In order to study mental states of patients, which can alter every moment, it is inevitable to use methodology based on psychopathology and nonlinear dynamics. Even if research at the molecular level claims to identify 'depression-related molecules' and their regulatory mechanisms, such information must be connected further to the macro-level phenomena of the individual, family, and society for actual prevention and treatment.

Style of cognition may alter physical conditions (the brain and genes) in the long term. It is therefore quite important that clinicians and researchers in biological psychiatry and psychopathology closely collaborate.

5-2 Adoption of virtual reality (VR) systems

Virtual reality is an effective means to reproduce, analyze, intervene in, or change situations where individuals, others and their environment interact with each other. Use of virtual reality in psychotherapy was proposed in 1993. Today it is used to treat phobias and eating disorders in

Europe and the USA.^[26-27] If a sense of immersion is sufficiently accepted as beneficial for humans, large-scale equipment is not necessarily required. For example, when patients arrived at the stage where they can use the equipment by themselves equipment that can be used in everyday living environments, such as HMDs (head-mounted displays) and PDAs, is expected to produce greater therapeutic results. In recent years, most VR systems can be sufficiently operated with ordinary personal computers. The emphasis of research and development has shifted to software, setting of cognitive and psychological contexts, and total framework.

In Japan, VR researchers have tended to focus on the development of large-scale equipment by accumulating state-of-art technologies. Furthermore, VR that focused on environmental settings seemed to have little relevance to brain science. However, because Brain Science has come to treat the environment as an inseparable entity from human cognition, VR is going to be studied within the framework of Brain Science. It is also expected that new VRs will be applicable in medical care and education by utilizing the knowledge, hypotheses, and methods of Brain Science.

Psychopathology addresses disorders that emerge through interactions of individuals with others and their environments and that cannot be thoroughly explained by genetics or pharmacology. In many cases, the clinical condition is inconsistent and the patients weaver between normal and pathological states. VR might be quite effective to elucidate the mechanism of this mental perturbation. Schizophrenia, depression, and bipolar disorders might be particularly suitable for research using VR. Tackling these issues would also provide a good opportunity to enhance software development and cognitive and psychological approaches in the research and development field of VR. Furthermore, activities of Japanese VR researchers often overlap those of robotics researchers. The field of robotics has already achieved mutual penetration with brain/neuroscience and cognitive science. Proceeding with research and development of systems integrating VR and robotics would be useful.

6 | Future Issues

6-1 *Innovation from the perspective of Brain Science*

The development of Brain Science has driven people to the point where the possibility to change authentic human psycho-neuro activity itself is discussed, even if the goal is not necessarily the treatment of disease. Here it is important to consider seriously what is the exact subject to be changed and what is “the natural state of human beings” in the first place. The present state of human beings is already a mixture of biological predisposition and accumulated artificial changes through social lives, knowledge and technology. Keeping this in mind, if one were to attempt to set criterion of the “natural state of humans,” there would be no universal answer. Each community would need to discuss the question by itself based on its geographical, historical and cultural backgrounds and make its own decisions. First, in order to do so, profound understanding of human evolution from the viewpoint of Brain Science is indispensable.

(1) **External memory**

In recent years, ‘external memory’ or ‘external brain’ is metaphorically discussed in information technology. From the perspective of cognitive archeology, however, humans have been producing external memory for at least 50,000 years.^[17] It is supposed that these phenomena were caused by the fact that the quantity of information humans dealt with had increased. The next issues are reasons that the amount of information increased, why humans increased the information they dealt with, and what caused its motivation.

(2) **Desire for innovation**

Some researchers in Brain Science and artificial life assert that human brains are structured with an inevitable desire for innovation.^[1, 2, 7, 28, 30] Other organisms also happen to use and modify their environments to match their cognitive patterns and to adapt themselves to their environments by forming new cognitive patterns.^[54] Humans, however, have a positive feedback cycle of “obtaining information,

developing technology thanks to the information, improving their environment, obtaining better and more information, and developing better technology using the latest information.” By bringing the natural environment under control and by ameliorating maintenance technologies of information, humans are about to escape from negative feedback and effectively shift into a monopoly of positive feedback.^[2] In order to control the desire for innovation, humans must elucidate mechanisms of positive feedback.

(3) Mechanisms of human desire

Approximately 30 years ago, engineers began to tackle new issues such as how to incorporate the structure of human desire into engineering. The belief was that "Invention was the mother of necessity" for a long time rather than "Necessity being the mother of invention" (KAWADA Junzo). As environmental and social problems surfaced, and the preservation of the global environment and ecosystems and the limits of natural resources were recognized, science and technology policy turned to put its priority to meeting social needs. In order to preserve the global environment and ecosystems, it is indispensable to understand the structure of human desire. The most plausible constraint for controlling the inevitable positive feedback of human brains would be, in turn, the necessity of preserving the global environment and ecosystems. New engineering and industries are necessary to reorient “the human desire for innovation” toward positive feedback for spiritual exploration from positive feedback based on consumption of energy and materials.

6-2 Long-term longitudinal (cohort) studies

Long-term longitudinal studies are important for studying the mechanisms by which personalities are built, and developmental disorders or mental illnesses manifest. The national government should take the lead in promoting such research.

When a human lifetime is overlooked, drastic integration and disintegration of various neural and physical systems take place especially during the fetal, newborn, and adolescent stages. A part of psycho-neuro disorders previously thought to be "innate" have only a low degree of penetration of genetic factors. Whether their phenotype

manifest or not may therefore depend on the process of integration or reintegration of neural and physical systems. If research focusing on developmental periods as described in section 3-3 brings about novel methods to detect and intervene developmental process of disorders antecedently, they may result in the prevention of pathogenesis in children with genetic risk factors. Furthermore, minor developmental disorders due to neurological causes do not have a distinct border with brain diversity and personality. Rather than simply aiming to "cure disorders," while considering that today's childrearing, education, and social systems are not necessarily optimized for human brain function, it is important to design research and development so that those systems can be improved.

It is therefore necessary to use long-term longitudinal studies beginning at the fetal and infancy stages to research not just the brain and nervous system, but also correlations among various elements, including social and environmental factors such as family and community. Because it is impossible to address every issue in education and healthcare from the beginning, it would be effective to narrow down subjects and begin with core subjects that can expand into a variety of themes in the future. Possible topics for initial study include the following.

- Nonlinguistic logic and memory and gestalt perception: Potential elucidation of the mechanism by which people obtain, with the actual feeling of ‘understanding,’ concrete knowledge grounded in one’s own memory, experience, and embodiment
- Development of individual modular perception and associative perception based on them: Potential elucidation of the development of reading, writing, and calculation abilities and their perturbation
- Analysis of the development of "theory of mind" and social conduct ability
- Analysis of the common points and differences of homozygote twins: Their differences in particular can contribute the analysis of psycho-neuro traits that emerge through interactions between the individual, others, and the environment rather than caused by genetic factors. First, research combining dynamic

analysis of the development of movement and perception with analysis of stress and depression in children would be significant.

Researchers participating in long-term longitudinal studies dedicate themselves to the research for a long time, and it may be difficult for them to publish articles while the research is underway. It is necessary to provide a protection and support system for researchers during longitudinal studies and for continuation of their careers after completion of their research.

When the government implements a long-term longitudinal study, it must explain any disadvantages or advantages associated with participation. Studies should be designed and operated so that subjects benefit over the long term through an increased level of awareness by participation.

First, it is important to promote careful and strict research in special research zones that take into account the geography and culture of the local communities. Once this gives favorable results, strictness of research conditions may be lowered to encourage the public to participate nationwide.

Nationwide longitudinal Brain Science studies in Japan have the following advantages.

Japan's advantages

- Japan is a relatively large linguistic area (9th in the world for a population using Japanese as mother tongue and 11th for a population using the language as official language, according to the Cambridge Fact Finder 1993).
- Japan has a relatively closed geographic environment.
- It has had a high literacy rate since the Edo period and people have had strong intellectual inquisitiveness.
- The Japanese people retain hunter-gatherer views of the world such as nature worship, ancestor worship and animism, in parallel with their successful modernization.^[5]
- Japanese people have strong propensities to surmise others' feelings and to modify their own comportment accordingly. Cognitive psychology tests produce different results than when given to Americans or Europeans.^[55-57]
- In psychiatry, Japan retains a therapeutic system based on psychopathology in which

medical doctors and patients have careful relationships.

- Japan belongs to the kanji culture sphere, which differs from Indo-European linguistic sphere. It is advantageous to carry out the linguistic research in situ and research on the expression and transmission of abstract concepts using integration of visual images and physical perceptions (e.g., calligraphy, SHIRAKAWA's kanji studies, and measures against reading/writing problems) are easy to perform.
- Japan has no significant ideological conflicts over Brain Science or the theory of evolution.

In order to promote Brain Science based on social needs under the social situation such that information is excessive, changes are rapid, and needs are diversifying, it is necessary to continuously collect large amounts of information. It is necessary to construct a system in which most of the public can voluntarily participate, release useful data, and utilize shared information. This could be the beginning of the construction of an information transmission and co-utilization system with a reliable foundation in science and technology.

6-3 *Spiritual affluence and Brain Science*

What does Brain Science today tell about pursuing or feeling affluence of the *kokoro*? The brain is not "the *kokoro*" itself, so it is quite unlike that a locus of "the *kokoro*" is found somewhere in the brain or that the state of "affluence of the *kokoro*" can be reduced to certain brain activities. This does not mean, however, that "affluence of the *kokoro*" is something that exists externally and is to be pursued there. Instead, some argue that the *kokoro* emerges at an "interface" where elements such as body and brain, self and others, and self and the environment interact. The brain should be related to this interface of emergence.

The first approach could be an investigation of the way in which "affluence of the *kokoro*" forms. Even when people completely forget what they heard, saw, felt, or said when experiencing music, travel, conversation, and so on, they often remember just that they enjoyed it. In such cases, meaning may have been created and transmitted through the structure of the interaction itself rather

than through its content. A typical example is the relationship between a baby and its caregiver. Babies do not understand what the caregiver says to them or the meaning of a smile. Because exchanges with the caregivers are positively felt, babies repeat the action and are gradually entrained into the caregivers' language games.

For music, research based on the premise that both novelty (deviation from expectations) and familiarity (conformity to expectations) are necessary, and that the fluctuation (timing and balance) between these factors make the listeners feel agreeable. Taking schizophrenia's suffering into account the formation of "affluence of the *kokoro*" may require confidence as if the self does not fluctuate even when one is actually entrained into fluctuating relationships. To be good musicians and interlocutors, a "theory of mind" is required. They do not merely transmit segments of music or language (predictability); they play or talk by anticipating "how the listener will interpret what I give them" and "what the listener will think about it" (deviation from predictability). It is becoming clear that fluent conversation requires proper turning of one's own gaze and literacy of interlocutors' gazes.^[13] Some of the common language confusions found in people with autism are also seen in children who are born blind.^[30]

What brings individuals a feeling of "affluence of the *kokoro*"? Comprehensive advancement of basic research from perspectives such as psychophysics, complexity, "theory of mind" research, psychiatry, and the humanities and social sciences will be useful. One approach to seeking affluence of *kokoro* could be the elucidation of the causes of schizophrenia and depression, whose sufferers are unable to pursue or feel the affluence of *kokoro*, and the reduction of those causes in society to the extent possible.

6-4 Research in the humanities and social sciences

Emphasis is shifting from the perspective that there is an objective external world and that knowledge consists of accurately knowing that world to the view that knowledge is created, that there are many valid forms of knowledge depending on observer, subject, and situation. In the world of science and technology, the methodology

of invention and discovery itself became a topic of study during the 19th century. During the 20th century, language to express knowledge itself became a research subject (Russell, Wittgenstein, etc.). In the 21st century, the creation of thought and knowledge, "understanding" itself, become a subject to be studied. The notion that knowledge is "created" is growing in importance. The school of thought prevailing since Descartes and Bacon, the idea that there is a universal, objective, external world, and that reliable knowledge can be obtained through validation methodology based on materialism and reproducibility, made a significant contribution to science and technology in the 19th and 20th centuries. On the other hand, different schools of thought such as those of G. B. Vico, TOMINAGA Nakamoto, C. H. Pierce, and G. Batson were studied in the humanities and social sciences. In Brain Science during the 21st century and thereafter, it is useful to put such research forward.

It was suggested scientifically by Brain Science that awareness of the "self" might be constructed and maintained through interaction with others and with communities. In addition, some Japanese researchers are reconsidering the notion of the individual that may have been overemphasized in the modern Western view of the self that was adopted in Japan during the Meiji period. Reviews of the history of the concept of the ego since the late Edo/early Meiji period have been performed in the fields of literature and psychopathology (pathography). These should be further pursued as part of Brain Science. Present brain/neuroscience has not yet developed a mature description of the self.

The cognitive patterns of humans today are constructed through a mixture of biological and cultural/social factors. Because cultural/sociological changes have been especially significant since humans began agriculture and livestock breeding approximately 10,000 years ago, the contributions of anthropology, history, and social science are important when the findings of Brain Science are applied to the actual world.

Databases of Japanese literature in the humanities and social sciences (e.g., articles in specialty journals, books, lecture records, anthologies, and digital media) should therefore be constructed and

maintained so that both experts and the public can use them. Databases with identifiable authors

should be kept upgraded.^[58]

6-5 Other relevant areas

Relevant area	Characteristics
Open platforms for understanding human behavior	The Digital Human Research Center's Open Life: Models of broad human cognitive behaviors are proposed by using, for example, Bayesian methods to analyze human subjectivity by applying elements usually considered difficult to use in statistical analysis. For example, children's body images and cognitive patterns have been surmised from adult perspectives before, but this platform can provide cognitive and behavioral models from the viewpoints of children at various developmental stages by taking the observations and insights of doctors and psychologists into account. It may also be used to develop accident prevention programs for children. ^[59]
Open software platforms for analysis of human behavior	The Research Group for Sociointelligence has already developed cognitive developmental robotics. Now, based on the National Institute of Informatics (NII), a software platform enabling participation by a broad range of users and long-term test series is being developed. The goal is to enable simulations that integrate perception, dynamics, and conversational behavior to allow various agents such as robots, virtual agents, and users (humans) to act in complex environments. NII is constructing multiple databases covering not only natural science but also the humanities and social sciences. Promoting effective integration of these elements would be significant. ^[58]
Ontology (philosophy and information science)	Terminology, knowledge, and concept from multiple areas are linked while preserving the descriptions of different knowledge systems in order to maintain the detailed implications of statements in each area comprising Brain Science.
Semantic editors	Based on the criterion that "if something is written so that a machine can understand it, then non-specialist humans can understand it as well," it is intended to allow non-experts in a specialized field to understand research results of the field by providing a standardized abstract of publications such as papers, books, lecture records, anthologies, bulletins, digital media, etc.
Use of information media for open peer review	Opportunities to present research based on visions, hypotheses, and embryonic ideas

7 Conclusion

Sustainable "maturity"

One issue that arose during the 1960s was social distortions due to "accelerated change." From a Brain Science perspective, a particular characteristic of the human brain is its irresistible propensity for innovation. When innovation itself becomes the focus of interest, exponential social change may take place. In the future, the creation of new policies to control the desire for innovation may become indispensable to maintain society, the global environment, and living systems.

UMESAO likened change in the 19th and 20th centuries to the growth of muscle and bone.

It is becoming universally obvious that the system that longed solely for growth through the industrialization of materials and energy is reaching its limits. Human beings must turn their irresistible desire for innovation inwards to develop spiritual industries and aim for maturity. Rather than worrying about the growth of just industrializing countries, Japan may be at the stage where it should dedicate itself to achieving maturity.

Today, it is necessary to reconsider issues that have remained unsolved since the 1960s and 1970s and seek solutions for problems that have grown more complex as well as new problems. It would also be meaningful to advance Brain Science from the perspective of elucidating life systems and maintaining ecosystems.

If human cognition patterns change through interaction with the environment, it would be possible to consider that human beings are still evolving, and even if it is unable to completely control the process, it may be possible to design evolution to orient to desirable directions. If humans have not yet evolved control functions for new abilities they had acquired, they must create internal mechanisms to control the positive feedback loop of information acquisition and its control. During discussion of "Innovation 25," some participants held that while technologies rapidly rise and fall and are therefore difficult to foresee the future based on them, fundamental human demands alter relatively little, so it is more reliable to foresee the future based on demands. Rather than enhancing human abilities or tolerance from the outside with novel technologies, machines, and medicines that appear available immediately, it would be better to improve the internal personality and social systems by pondering what kind of existence we long to be and what kind of world we wish to live in. It is quite important to manage Brain Science *lato sensu* to contribute to this process.

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