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Abstract

This paper discusses mathematical literacy for lifelong intellectual enrichment in the 21st century based on the findings of the Project "Science for All", which has been carried out over the past several years. First, an overview of mathematical literacy in the world and in Japan will be given. This will be followed by a discussion touching upon scientific and technological literacy and mathematical literacy as delineated by the Project "Science for All". Following these discussions, mathematical literacy is defined as: "the knowledge, skills, and ways of viewing mathematics that all adults are expected to possess." And mathematical literacy will be considered from three viewpoints, namely: a society of lifelong learning, a sustainable and democratic society, and a society that values learning mathematics. Further, keeping mathematical literacy in mind, it will be made clear that mathematics education in school should be reconsidered from three viewpoints: 1) thinking about learning as a lifelong activity, 2) preparation for future endeavors and enjoyment of learning, and 3) integration of academic cultures.

Keywords: *mathematical literacy, scientific and technological literacy, Project "Science for All"*

Introduction

As we entered into the 21st century, the crisis of the earth's sustainability became the subject of public outcry. We are called on, as a society, to grapple with many such issues in a democratic way. Especially in modern society, where the role of science and technology is of vital importance, scientific and technological literacy is expected of all adults. However, "the drift away from science", "the drift away from mathematics", or "the drift away from science and technology" has become a matter of great concern not only among children, but also among adults. This surging trend as a whole has been dubbed "the drift away from knowledge." Now we are compelled to re-visit and re-evaluate the way which science, mathematics, and technology education in Japan is implemented. Thus, mathematical literacy will be used as a framework for critiquing mathematics education in both school and society.

In this paper, the concept of mathematical literacy for lifelong enrichment will be investigated and clarified. Based on this clarification, as well as the results of the project on scientific and technological literacy that began in 2005 in Japan, the significance and future state of mathematics education will once again be re-considered. The author took a part in the project as a member of its research team.

An Overview of Discussions of Mathematical Literacy in the Past

From 2005 to 2006, "Research on Building Scientific and Technological Literacy" was conducted. This study examined the current states of scientific, mathematical and technological literacy in Japan, several foreign countries, and international institutions. In addition, it delved into the significance and necessity of literacy, as well as the organizational systems for developing literacy (Kitahara, 2006; Nagasaki, 2006). This project was conducted with funds from a Science & Technology Advancement Grant with support provided by International Christian University (ICU), the National Institute for Educational Policy Research of Japan (NIER), Ochanomizu University, and the Science Council of Japan (SCJ). The project was headed by a physicist, Prof. K. Kitahara of ICU, and included about seventy scientists, and educators.

In this project, surveys were made on the current states of scientific and technological literacy in different countries including the USA, Canada, England, and China, as well as in world organizations such as UNESCO, and OECD. In particular, Project 2061 of the American Association for the Advancement of Science (AAAS) and its study "Science for All Americans" (AAAS, 1989) were investigated in detail. Furthermore, research on mathematical literacy by Dr. E. Jablonka was also examined. This paper focuses on findings from these surveys and investigations as they relate to mathematical literacy (Abe, 2006) for the purpose of discussion and to give an overview of mathematical literacy in the up to the present.

Mathematical literacy in the world

Dr. Jablonka analyzed and recapitulated ideas on typical mathematical literacy in the world into five categories (Jablonka, 2003). The five categories are summarized as follows:

1) PISA for developing human capital: problem solving ability for social development, 2) Ethno-mathematics for cultural identity: unique non-school mathematics for social maintenance, 3) Critical mathematics for social change: critical abilities for social change, 4) Environmental issues for environmental awareness: mathematical modeling for awareness of social problems, 5) Critique of mathematics for evaluating mathematics: consciousness for reliability of mathematics.

According to five ideas of mathematical literacy recapitulated by Dr. Jablonka, there are at least three viewpoints for considering mathematical literacy. The first, there is its relation to society, such as maintenance, development and change of society. The second is understanding of mathematics, such as mathematics as a tool, and mathematics as an object for evaluation. The third is the content of mathematical literacy, such as basic knowledge and skills of mathematics, problem solving ability, mathematical modeling, and critical abilities.

Mathematical literacy in japan

In Japan, there are various words associated with "literacy" [*riterasi* in Japanese], namely the "three R's," reading, writing, and arithmetic [*yomi-kaki-soroban*], "culture" [*kyouyou*], "basic practical skills" [*soyou*], and "comprehension" [*rikairyoku*]. In this section, mathematical literacy in Japan is overviewed together with those terms mentioned above.

In Japan, the term "mathematical culture" was used in the national course of study for mathematics education in upper secondary school published in 1955, and ways of mathematical thinking were shown as examples of mathematical culture. Since then, there has been almost no discussion of mathematics culture or mathematical literacy in mathematics education. In the 1980's, discussions on literacy arose in response to change of upper secondary school and society, and computer literacy, information literacy, and media literacy continued to discuss until the mid 1990's. During this period, although there were some discussions on mathematical literacy in the latter half of

1980's, there were not so many of them. Until the mid 1990's, there was a mixture of various discussions on mathematical literacy (including NCTM's views), matheracy, numeracy, mathemacy, quantitative literacy, and statistical literacy. Since the beginning of 2000 until now, mathematical literacy according to PISA has been the core of various discussions.

Among these, there are three types of literacy that seem to be very unique to Japan. They are: 1) mathematical literacy for fostering intelligence in the majority of upper secondary school students, 2) matheracy, and 3) mathematical literacy for ordinary citizens in a highly information-oriented society.

Mathematical literacy for fostering intelligence in the majority of upper secondary school students - the number of students was sharply increased - was advocated by a mathematician, Prof. H. Fujita, in 1983. According to Prof. Fujita, it is important to foster mathematical intelligence in upper secondary school students. He thought that mathematical intelligence was composed of mathematical thinking and mathematical literacy, and that mathematical thinking was necessary for those students who wanted to become specialists in the future, whereas mathematical literacy was necessary for the remaining majority of students. He assumed that mathematical literacy included knowing certainty of mathematics and clearnesss of mathematical logic, and ability to apply mathematical concepts for scientific language activities at the ordinary citizens' level.

Matheracy, which is derived from mathematical literacy, was advocated by then president of JSME, Prof. T. Kawaguchi in 1983. Matheracy was an idea for curriculum construction based on mathematical cognitive activities as methods. It also categorized mathematical content into four categories, namely, objects, activities, inferences, and problem solving activities that integrated the other three. Here, aims and objectives of the curriculum were explained based on the existing premises, and activities were described as the core of educational content and methods.

A report on mathematical literacy for ordinary citizens in a highly information-oriented society was made by an ad-hoc committee of the JSME in 1987. In the report, mathematical literacy and computer literacy were discussed in connection with a highly information-oriented society. Discussions on mathematical literacy were developed into discussions on computer literacy as a response to the shift toward a highly information-oriented society.

As to discussions on mathematical literacy in Japan, although some attempts were made to pursue something unique to our country, the discussions became influenced by NCTM's and PISA's mathematical literacy. After all, ideas on mathematics literacy in Japan were understood within school education, and there was no consensus that the target was "each and every" student. Also, the discussions lacked a sense of how the attempts should cope with society. Thus, the discussions were unable to embody mathematical literacy.

Learning from the Project "Science for All"

Background on the project "Science for All"

The Project "Science for All" defined "Scientific and technological literacy" during 2006 - 2008, following the research mentioned in Section 2 (Project "Science for All", 2008a). In the project, "Scientific and technological literacy" was defined as "the knowledge, skills, and ways of viewing science, mathematics, and technology that all adults are expected to possess." Also, human science, social science, and informatics were included in "Scientific and technological literacy."

This project was conducted with funds from a Science & Technology Advancement Grant with the support of the Science Council of Japan (SCJ) and the National Institute for Educational Policy Research of Japan (NIER). The project representative was Professor K. Kitahara of International Christian University (ICU), and about 150 members, including scientists, engineers, educators, science museum personnel, members of the media, and various NPO's took part in the project. The author of this paper served as Secretary-General of the Secretariat.

The project organization was made up of a Council, a Planning and Steering Committee, seven Special Subcommittees, a Publicity Subcommittee, and a Secretariat. The seven Special Subcommittees were comprised of committees for Mathematical science, Material science, Life science, Informatics, Earth, space and environmental science, Human and social science, and Technology. Each special subcommittee was composed of about fifteen members. Over the course of the project, scientific and technological literacy were investigated among members alone, but we aimed to have as many people as possible participate via the website and symposiums, so that the project itself could become a movement to enhance scientific and technological literacy.

The need for scientific and technological literacy

The Project "Science for All" drew an image of what we want Japan to be like in the future. According to this image of the future Japan, 1) every individual should be recognized as an irreplaceable member of our society, 2) every member of our society should care for planet Earth, share wisdom and take action toward the realization of sustainable society, and 3) our society should be equipped with an effective system in which young people can entertain hope for the future and inherit a culture. We decided that we must make scientific and technological literacy a reality for the enrichment of the Japanese people and for a sustainable and democratic society.

We believe that the significance and need to define scientific and technological literacy lie in the following four objectives:

a. To make judgments concerning science and technology,
b. To transmit scientific knowledge over generations,
c. To provide a coherent, long-term perspective for primary and secondary school education in science, mathematics, and technology,
d. To convey the sense that learning, including the learning of science, mathematics, and technology, is a lifelong activity.

We expect that the project and its results will serve as a guide for the understanding of science, mathematics, and technology as prerequisites for various objectives, as the foundation for developing materials for science, mathematics, and technology education, and as a driving force to promote public understanding of science, mathematics and technology.

Delineating scientific and technological literacy

In 2008, the "*Integrated Report on Scientific and Technological Literacy*" and seven "*Summary Reports*" on scientific and technological literacy prepared by special subcommittees were published.

The recent progress of science and technology, as well as characteristics of Japanese culture, was incorporated in defining literacy. In preparing the framework for the reports, we made an effort to build its framework with human society at the core, and to include perspectives from the present and the future.

The Integrated Report on Scientific and Technological Literacy is composed of six sections, of which four are main sections. These four main sections are titled, Essence of Science & Technology, Science for All - Seven Doors-, Perspectives of Science for All, and Application of Science for All. Details of each section are as follows: (Project "Science for All", 2008a, 233p).

Section 1. Towards Science for All and Lifetime Enrichment in the 21st Century

Section 2. Essence of Science & Technology: *Essence of science, Essence of mathematics, Essence of technology.*

Section 3. Science for All - Seven Doors-: *Mathematical science, Material science, Life science, Informatics, Earth, space, and environmental science, Human and social science, Technology.*

Section 4. Perspectives on Science for All: *A Modern perspective on nature and methodology, Historical facts that brought about change in science and technology:* Scientific understanding of human beings, The information processing revolution, Nanotechnology, Elucidation of the mechanism of life and development of manipulation technology, Establishment of the cosmological model, Scientific understanding of the global environment. *Modern ways of thinking about science and technology:* Choice on integrated view, Diversity and uniformity, Visualization, how image building change our science and everyday life, Scale and size, Algorithm for high-speed processing of mass volume data, Mutual contributions of science and technology, *Scientific attitudes and sense.*

Section 5. Application of Science for All: Four Topics: *Natural science of water, technology for utilizing water, and water and human life, Food, establishment of supply quantity and safety, Energy, the power source driving nature and society, The earth and the human domain.*

In addition, to facilitate understanding, a *Mandala* schema was created by each special subcommittee to illustrate scientific and technological literacy.

The Summary Report of the Mathematical Science Subcommittee is composed of five sections as follows: Essence of Mathematics, The World of Mathematics (A): Objects and Important Concepts of Mathematics, The World of Mathematics (B): Methods of Mathematics, Several Topics, and Relation of Mathematics with Humanity (Project "Science for All", 2008b, 233p; Namikawa, 2009). The committee was headed by Prof. Y. Namikawa, a mathematician. The contents of each section are summarized below.

Section 1. Essence of Mathematics: *Foundations of mathematics consisting of numbers and figures, Mathematics systematizes abstract concepts with logic, Mathematics is descriptive language with emphasis on abstraction and logic, Mathematics is open to all sciences as a study of universal structures -mathematical models-.*

Section 2. The World of Mathematics (A): Objects and Important Concepts of Mathematics: *Number and quantity, Geometrical figures, Change and relation, Data and certainty.*

Section 3. The World of Mathematics (B): Methods of Mathematics: *Mathematics as a language both verbal and graphic, Mathematical methods of solving problems and constructing systems of knowledge.*

Section 4. Several Topics: *Logical thinking, Numeration system and notation system, Infinity, Circle ratio π and base of national logarithm e, Symmetry, Audience rating, Normal distribution, Japanese language and mathematics, Japanese mathematics in the Edo period: Wasan.*

Section 5. Relation of Mathematics with Humanity: *Relation of mathematics* *with individuals, Relationship between mathematics and human society, Relation of mathematics to natural science*

Further research for mathematical literacy from the project "Science for All"

This was the first such attempt at bringing about scientific and technological literacy in Japan. These publications should be revised and appropriately rewritten for different audiences. The Project "Science for All" is still actively disseminating their findings on literacy, and the results of the Project have been published in various magazines, such as the Journal for the Japan Society for Science Education (JSSE, 2008).

Also, mathematics educators who have participated in the Project "Science for All" have begun to engage in ongoing research with focuses on mathematical literacy (Iwasaki, 2010; Shimizu, 2009). I have been involved in one of these ongoing research projects on mathematical literacy. Through such research, I have been able to gather many ideas, which I would like to share.

Perspectives for Considering Mathematical Literacy and Lifetime Enrichment in the 21st Century

The Project "Science for All" advocated scientific and technological literacy for lifetime intellectual enrichment, aiming for the realization of sustainable and democratic society. I began to consider mathematical literacy from similar points of view as the project, namely that mathematical literacy means "the knowledge, skills, and ways of viewing mathematics that all adults are expected to possess." Here, I want to bear in mind that "all adults" is a key phrase for mathematical literacy. Of course, "all" is a symbolic expression and means that mathematics literacy is for all adults, and not only for some.

On this standpoint, mathematical literacy for lifelong intellectual enrichment in the 21st century can be considered more concretely from three viewpoints: demands of modern society, challenge for the future, and present needs of mathematics education in Japan.

The demands of modern society: a society that supports lifelong learning

In any society, dealing with numbers, quantity, and geometrical figures is an essential part of everyday life. Even if specific details change with the times, this type of basic knowledge and skills will be central to the mathematical literacy that all adults are expected to possess.

On the other hand, modern society is considered highly information-oriented, and lifelong learning and a new type of mathematical literacy are needed for everyday life. Methods of mathematical expression and thinking which are considered to be part of mathematical literacy can be useful in society. When we talk about mathematical skills, we can mention calculation skills or problem solving skills. However, we also think that more diverse abilities can be acquired through learning mathematics (Nagasaki et al, 2008). Furthermore, appreciation of the cultural significance and value of mathematics (Bishop, 1988), as well as enjoyment of mathematics, will be included in mathematical literacy.

A Challenge for the future: A sustainable and democratic society

The Project "Science for All" depicted the Japan of the future as a sustainable and democratic society. The building of a sustainable society is a challenge of the 21st century, while construction of a democratic society is a continuing challenge that has been carried over from the 20th century. In order to preserve the global environment and construct a sustainable and democratic society, each and every adult is asked to think and make a judgment about problems. To this end, scientific and technological literacy is required.

Thus, knowledge of the role of mathematics in a scientific and technological society, knowledge of the relationship between mathematics and science and technology, and ability to develop mathematical models as a process to solve a mathematical problems in the real world are required in mathematical literacy. Furthermore, the ability to think statistically and critically is considered mathematical strength in a democratic society.

Present Needs Regarding Mathematics Education in Japan: A society that values learning mathematics

Japanese children, according to PISA and TIMSS, do not enjoy learning mathematics and also seem to have forgotten the true meaning of learning mathematics. The fact is that they do not find learning mathematics important unless mathematics is the optional subject in an entrance examination. This seems to imply that Japanese society in general has forgotten the significance of learning mathematics.

Acquiring knowledge about the significance of learning mathematics as mathematical literacy will prompt the formation of a consensus on the significance of learning mathematics. This will encourage children to set about learning mathematics in its original sense. In order to get Japanese mathematics education out of the mindset of "mathematics for entrance examinations" (Hirabayasi, 2004) or "mathematics as a sieve" (Howson et al, 1981) so that both adults and children enjoy learning mathematics in its true sense, we must aim to build a society that values learning mathematics (Nagasaki et al, 2007), even if that goal seems far off.

Mathematics Education with a Focus on Mathematical Literacy

When we think about developing mathematical literacy, mathematics education in school should be reconsidered from three viewpoints, namely, taking people's lifetimes into account, learning out of interest or in preparation for future endeavors, and the integration of various academic cultures.

Taking people's lifetimes into account

Thinking about mathematical literacy, we begin to formulate a plan for mathematics education that takes people's lifetimes into account (Lengrand, 1970). It is clear that this differs from the "mathematics for entrance examination" or "mathematics as sieve" mindset. We must break out of the vicious circle of "the harder we work on mathematics education, the more people do not like mathematics." Since mathematical literacy takes people's lifetimes into account, it is our hope that children will learn mathematics of their own free wills.

Taking people's lifetimes into account means that we should not think of education as completed at school. People continue to learn even after they go out into society. Educational systems must be changed in accordance with this viewpoint, and individual awareness must be raised. In teaching and learning, we must connect with the real world and continue to teach in a spiral.

Preparation for future endeavors and enjoyment of learning

With an awareness of mathematics literacy, we can see that there are two aspects of the curriculum for general education. One is preparation for future endeavors, and the other is enjoyment of learning in the present. To put it another way, there is learning content for preparing for the future and learning content that we do not typically expect most adults to retain. With the latter type of learning content, children can engage in appropriate mathematical activities. That is to say, through mathematical activities, children can enjoy learning according to their own wills.

However, we cannot make a clear distinction between these two aspects when we teach. From the standpoint of mathematical literacy, therefore, we need to examine three aspects of teaching mathematics, namely, teaching focused on preparing for the future, teaching focused on enjoyment of learning, and teaching focused on both. Learning content related to mathematical literacy needs to be taught repeatedly in different ways and in various situations.

Integration of various academic cultures

Mathematical literacy integrates general mathematics education for all adults and mathematics education for those who go on to pursue science and technology or to use or to advance mathematics in the future. The Essence of mathematics and the examples of utilizing mathematics, which are important elements of mathematical literacy, are useful not only for all adults, but also for those who go on to pursue science and technology because it gives them an overview of their future career. Also, through learning out of interest, people who go on to science and technology can obtain knowledge, skills and ways of thinking required for science and technology.

Thus, the two cultures of science and technology and the humanities (Snow, 1964) as well as theory-oriented and application-oriented in mathematics education can be integrated by mathematical literacy. Further, since the object of mathematical literacy is all adults in a democratic society, cooperative learning among heterogeneous groups of children is imperative. This idea is connected to the idea of "Interacting in Heterogeneous Groups" in OECD's concept of key-competencies (Rychen et al, 2003). Mathematical literacy will integrate these diverse cultures.

Conclusion

Further efforts are needed for developing mathematical literacy for lifelong intellectual enrichment in the 21st century based on the discussions in this paper. First, we must establish a concrete image of mathematical literacy and show processes involved in planning to establish the image. Next, a new curriculum must be developed for schools. For this undertaking, we must shed new light on educational content, methods, and evaluation. Changes in teacher education, out-of-school education, and the framework of mathematics education itself as an academic subject will be urged. More than anything else, we will have to answer questions about the way our society should be.

Our project will further pursue what mathematical literacy should be in Japanese society, making the best possible use of the results of the Project "Science for All".

I express my sincere gratitude for Ms. Michiko Lucy Nakagawa's support.

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