Problem Research and Use of ICT in Mathematics Education

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Abstract: *In Japan, standards have been established for curriculum organization. In this paper, we describe the standards and the transition of the use of ICT. We also discuss the SSH project (Super Science High School), a national project to promote science and mathematics education, and present a case study of the use of ICT in one of the educational activities in the project, based on the author's experience, and describes its educational effects. Furthermore, based on the discussion of the case study, the direction of the use of ICT in statistics and mathematics education in the future will be proposed.*

1. Introduction

In Japan, there are curriculum standards called "Courses of Study," which have been established by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) to ensure that a particular standard is maintained in all schools throughout Japan. These standards stipulate general curricular considerations, the number of class hours, and each subject area's general goals, contents, and content. Each school determines the textbooks and timetables for its students based on these standards. The Courses of Study are reviewed every ten years to indicate the qualities and abilities necessary for children to live, and to consider social changes such as globalization, rapid informatization, and technological innovation. In high schools, education under the new Courses of Study will begin in 2022, and "inquiry" has been identified as a keyword for learning in the overall curriculum.

In addition, in this revision, science and mathematics education is required to enhance learning activities for scientific inquiry through observation, experimentation, and statistical education for analyzing data and solving problems.

Therefore, this paper focuses on "inquiry" learning activities in science and mathematics education and efforts to enhance statistics education. The inquiry process involves problem setting, information gathering, organization and analysis, and summarization and expression. We believe that one of the educational activities that participate in the inquiry process is the Problem Research[*1] conducted at Super Science High Schools (hereafter, SSH[*2]). Based on our experience working at SSH-designated schools from 2008 to 2020, we will summarize the changes in the Courses of Study and the status of the use of ICT and introduce examples of the use of ICT in Problem Research. We want to discuss the case studies from the viewpoint of statistical education and make suggestions for future statistical education and the use of ICT.

2. Changes in the Objectives of Mathematics and the Use of ICT

We summarized the objectives of the mathematics department in the Courses of Study from the time when the SSH project started to the present. We focus on how the objectives are expressed in terms of what kind of skills students should acquire through the study of mathematics. At the same time, we summarize the efforts and the status of the use of ICT at A High School.

2.1 Objectives of Mathematics*[3] and Classroom

Notification period Implementation period	**Objectives of Mathematics *[3]**	**Classroom Practice**
Notification in March 1999 Implemented on an annual basis since 2003	To help students deepen their understanding of the basic concepts, principles, and rules of mathematics, to develop their ability to think and express phenomena mathematically, cultivate a basis for creativity through mathematical activities, recognize the values of mathematical ways of seeing and thinking and develop an attitude to use these values actively.	[Class] Do not use ICT. [Equipment] No screen or projector in the classroom. Teachers bring their own it. A wired LAN is gradually being installed.
Notification in March 2009 Implemented on an annual basis since 2013.	Through mathematical activities, to help students deepen their understanding of the basic concepts, principles, and rules of mathematics, develop their ability to think and express phenomena mathematically, cultivate a basis for creativity, recognize mathematical values, and develop an attitude of making judgments based on mathematical arguments by actively using these values.	[Class] Use graphing software for presentations and conduct classes in the computer room. In Problem Research, students use tablet PCs in groups to search the Internet and use Excel and PowerPoint. Use graphing and geometry software and a graphing calculator.

Goals of the Mathematics Department in the current Courses of Study and the current ICT environment in schools

Notification in March 2018 Implemented on an annual basis since 2022	The goal is to develop the following qualities and abilities to think mathematically through mathematical activities, using mathematical ways of seeing and thinking. (1) To understand the basic concepts, principles, and rules of quantity and shape, and to acquire the skills to mathematize, mathematically interpret, mathematically express, and mathematically process phenomena. (2) Cultivate the ability to examine events logically using mathematics, to find properties of quantities and figures and to examine them in an integrated and developed manner, and to express events concisely, clearly, and accurately using mathematical expressions. (3) Cultivate an attitude to think persistently and apply mathematics to daily life and learning by realizing the enjoyment of mathematical activities and the value of mathematics and evaluating and improving the problem-solving process in retrospect.
The school environment	Each student is given one tablet PC and a Google account. Each classroom is equipped with a projector, screen, and Wi-Fi network. Both students and teachers can use it every hour.

2.2 Promotion of teaching through mathematical activities

From the changes in the Courses of Study to date, it can be seen that "mathematical activities" are of great significance in mathematics education in Japan. Furthermore, in those activities, ICT is practical and currently indispensable.

"Mathematical activities" are activities in which the students conduct the learning process of arithmetic and mathematics. The image of this is shown below (see [1]).

It is described as moving between the real world and the world of mathematics. In the real world, the student can perceive everyday life and social events mathematically, process them mathematically, and solve problems. One can think about mathematical events in an integrated and developed manner and solve problems. These processes are shown to move between the real world and the mathematical world by focusing on the problem expressed mathematically and obtaining results.

The Problem Research is an activity that can realize this learning process and we have been practicing it. The following is an example of practice with ICT.

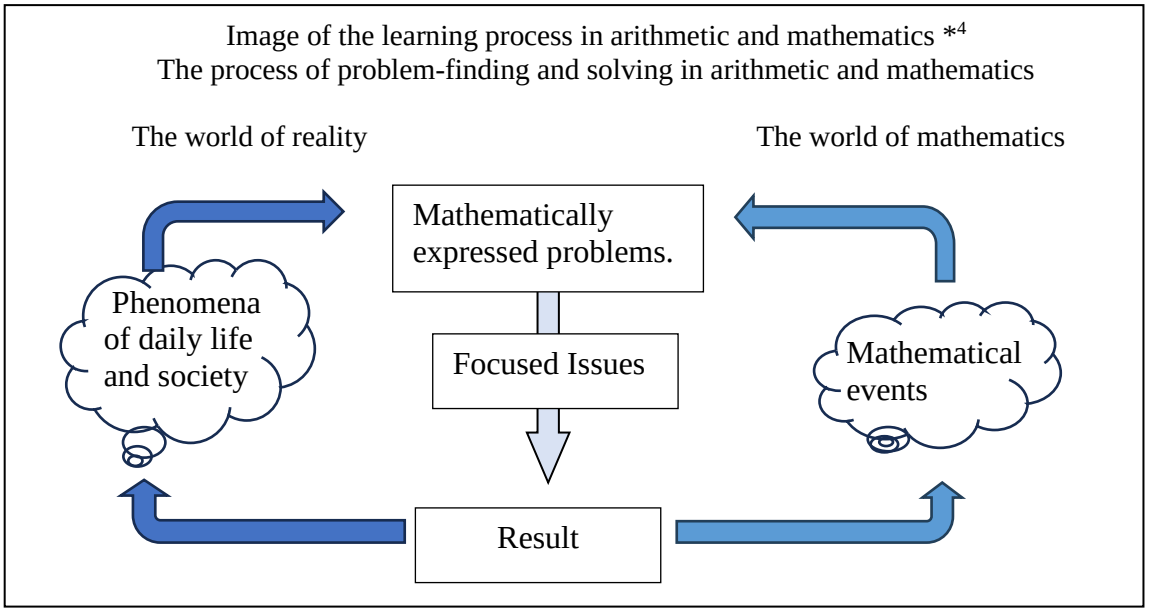

Figure 2.1 Image of the learning process in arithmetic and mathematics*[4]

3. The practice in Problem Research at SSH school

The author worked at two SSH schools, the first being School A (April 1, 2008-March 31, 2015), currently in its Phase IV designation as an SSH-designated school. The author worked at the time of the I and II designations.

The second school is School B (April 1, 2016 - March 31, 2020), currently in its Phase Vth designation as an SSH-designated school. The author worked at School B during the IV designation. In both cases, Problem Research on an issue is positioned, and students set an issue and research it individually or in groups. In addition to delving deeply into specialized content in mathematics, there is a strong tendency to use mathematics to research issues. The author describes the classroom practice at School A.

3.1 Class Outline

3.1.1 Problem Research: "Data analysis of photovoltaic power generation and its future use"

Solar panels were installed on the roof of the school building, and temperature, solar radiation, and the amount of electricity generated were measured, these data had been stored on a computer in the school since March 2004. Students learned of the existence of this data and analyzed it. The computer spreadsheet software Excel was used.

Students were interested in energy issues. Since solar power generation has been attracting attention from all over the world as an environmentally friendly method of power generation, and research has been conducted to improve its efficiency, they investigated, based on data accumulated at the school, whether solar radiation is proportional to power generated, whether the temperature is related to power generated, and what can be done to improve the efficiency of power generation, and what should be done to improve the efficiency of power generation. As a method, data on electricity generated by solar panels was imported into a computer and graphed for annual and monthly comparisons. The following data dealt with the data at that time.

date	solar radiation (kwh/m²)	temperature (℃)	the amount of electricity generated (kwh)
1	1.476	23.8	14.41
2	0.893	20.9	7.96
3	4.233	23.8	40.35
4	4.845	23.9	44.77
5	5.471	26.2	50.68
6	4.79	26.8	44.29
7	3.991	28.9	37.06
8	2.191	27	20.76
9	2.408	27.7	22.97
10	1.827	25.4	17.52
11	3.377	25.6	33.16
12	4.457	27.1	41.39
13	2.278	27.6	21.24
14	4.458	30	40.92
15	3.468	28.7	31.61
16	1.888	24.3	17.55
17	2.098	25.6	19.42
18	2.133	26.9	20.36
19	1.975	27.3	18.45
20	4.291	26	39.99
21	1.69	26.3	16.67
22	3.524	26.1	33.68
23	2.18	23.8	20.36
24	3.697	26.8	35.06
25	1.872	27.3	18.03
26	2.594	25.4	24.37
27	2.503	25.3	23.43
28	1.897	25.2	18.58
29	3.774	28.8	35.45
30	2.275	24.9	21.14
31	1.974	24.4	18.91

Figure 3.1 Data of photovoltaic power generation

The data on solar radiation, temperature, and electricity generated were graphed. The graphs were graphed over a day to identify trends. The weather was also used as a reference. There were differences between sunny and rainy days. (See [1] and [2], [3]) On sunny days, the amount of solar radiation and electricity generated were higher than on rainy days.

In addition, a similar graph was made to grasp the trend to know the annual change. There were differences depending on the season.

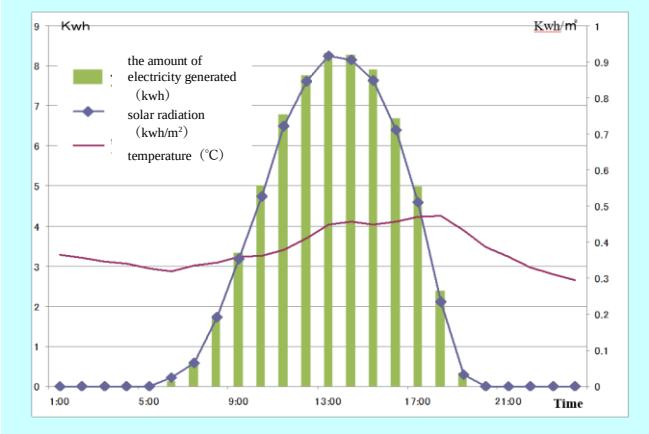

Figure 3.2 Graphs of the amount of electricity generated, solar radiation and temperature (sunny)

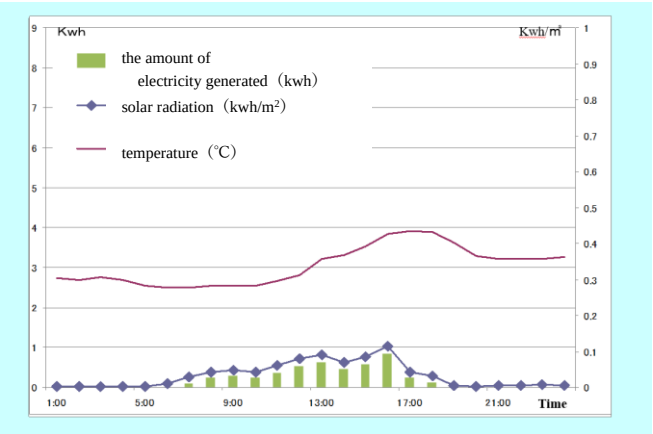

Figure 3.3 Graphs of the amount of electricity generated ,solar radiation and temperature (rainy)

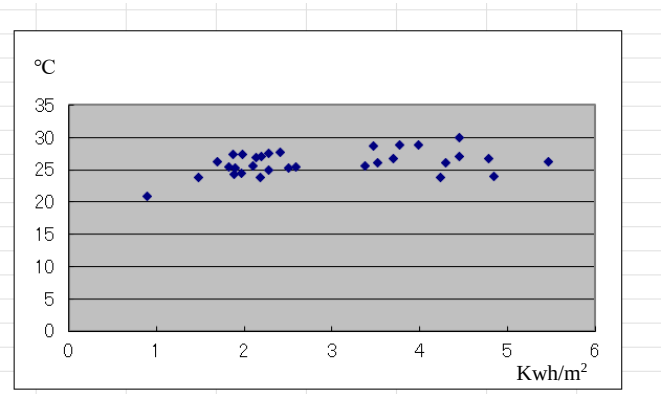

Figure 3.4 Scatter diagram of temperature and solar radiation

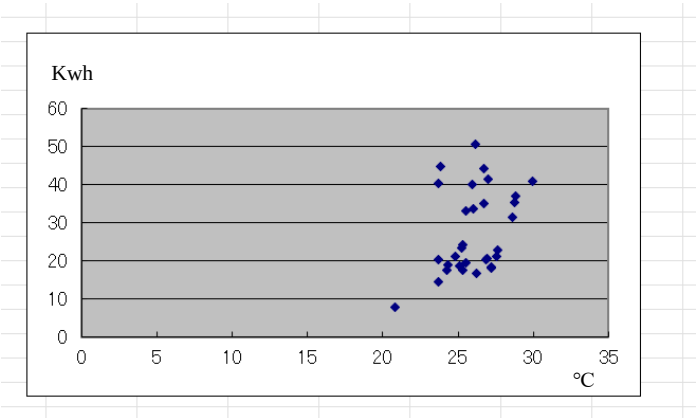

Figure 3.5 Scatter diagram of the amount of electricity generated and temperature

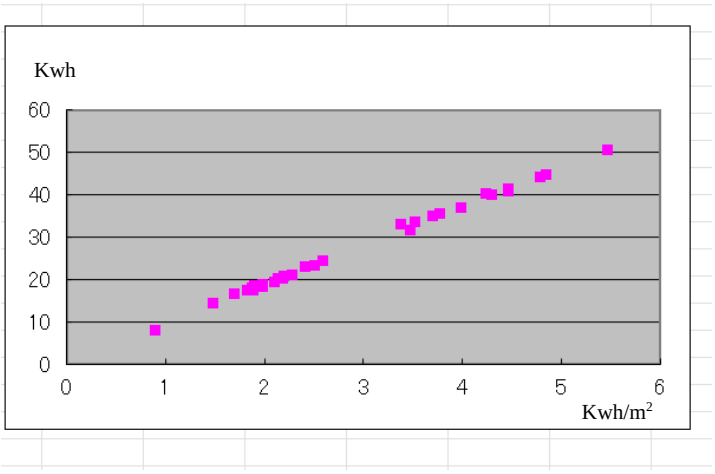

Figure 3.6 Scatter diagram of amount of electricity generated and solar radiation

Next, Students also examined the correlation between average monthly temperatures the amount of electricity generated, and solar radiation to determine whether temperature affects them. Scatter plots were created using data from the past five years. It was found that there is no direct relationship between temperature and the amount of electricity generated and between temperature and solar radiation. (See [4] and [5])

Regarding solar radiation and electricity production, data analysis from the past five years shows they are proportional. These were compiled throughout the year. (See [6]) This indicates that the amount of solar radiation affects the electricity generated.

As a discussion, the graph shows that the shape of the graph is mountainous in shape in all years, indicating that the summer season tends to have higher temperatures, solar radiation, and electricity generation. The reason for the lower amount of electricity generated from November to February, the winter season, was that geographical factors resulted in fewer sunny days due to higher winter precipitation. A new finding was that electricity generation was higher in the spring months of March through May, rather than in the summer when there are more sunny days. They were able to confirm that in some years this was beyond the summer months. Typhoons and fall rains influenced the lower amount of electricity generated in September in the fall, while the higher amount in October could be attributed to the influence of clear autumn weather. It was also found that there is a correlation between the amount of solar radiation and the amount of electricity generated, which can be said to be proportional to the amount of electricity generated.
(See [7] and [8])

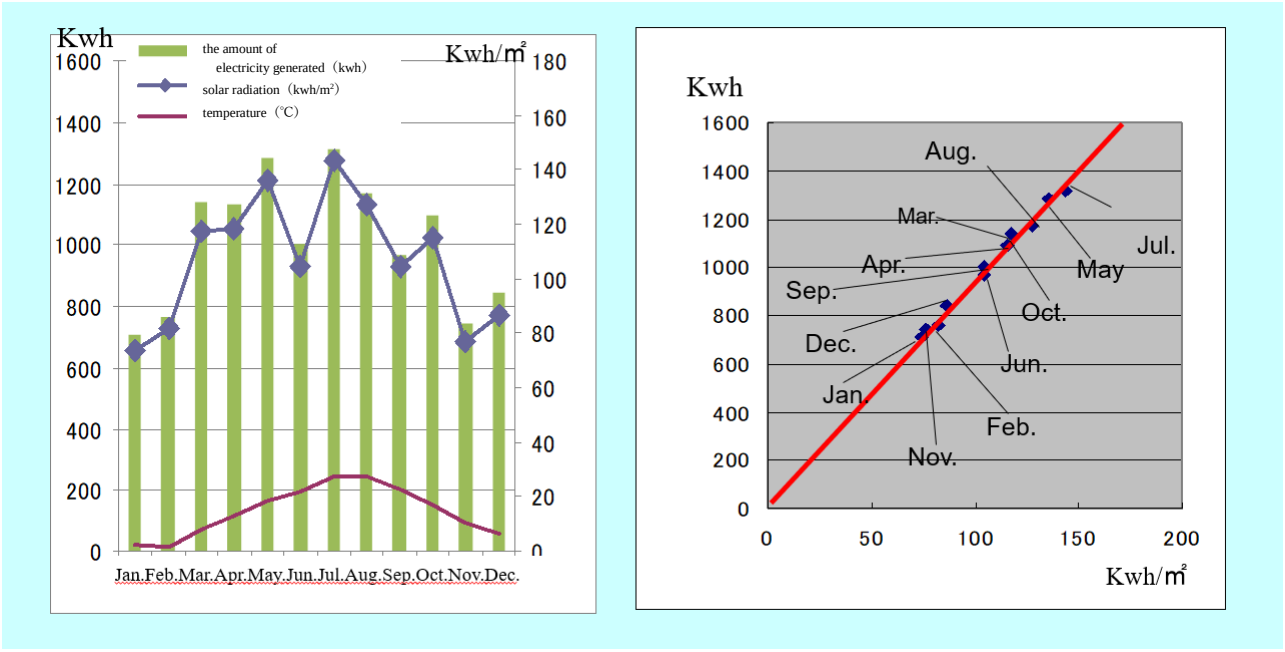

Figure 3.7 Graphs of the amount of electricity generated, solar radiation and temperature (year)

Figure 3.8 Scatter diagram of the amount of electricity generated and solar radiation (year)

For future development issues, Students said that would like to research the relationship between solar panel temperature and power generation efficiency, the relationship between weather and power generation, and confirmation of whether there is a relationship between light wavelength and power generation capacity based on measurements of changes in power generation at different light wavelengths and whether it is practical to install solar panels in homes, considering installation costs and electricity costs. The difference in the amount of electricity generated by solar

panels and irradiation angles. Since the panels become hot while the sun is shining, they would like to research more effective solar panels, including the use of solar heat.

3.1.2 Course "Fundamentals of Mathematics"

The goal of the course is two points:

1. Acquire knowledge and skills in data processing using a personal computer.
2. Acquire methods to analyze data accurately.
3. Acquired the ability to process and read information accurately and develop an attitude to apply it to real life.

The course aimed to give students with the basic knowledge and skills necessary to research an issue. To acquire the basic knowledge and skills necessary for research, the students used presentation software using a PC and spreadsheet software in data processing to write a report using a PC. The students experienced the hypothesis, verification, and summary process in the computer room.

3.2 Consideration of Classroom Practice

Problem Research 3.1.1 is an issue study where the mathematical activities described in 2.2 can be practiced. This example of setting an issue is from familiar data, formulating a hypothesis, analyzing, and verifying it, summarizing the results, and discovering a new issue – the case study of using ICT in this process. By using ICT to process a large amount of data, they could find relationships that confirm the results of previous studies and discover the characteristics of the area in which they live and future issues based on these characteristics. Data analysis brought the mathematical world closer together in familiar places in the real world.

ICT is effective in advancing research using data, and course 3.1.2 is a case study aimed at developing a foundation for actively using ICT to use data.

ICT was actively utilized in both cases to promote the Problem Research further. Next, since "data analysis" is a common theme in these cases, we will discuss them from the viewpoints of statistical education and the use of ICT.

3.3 Consideration from the Perspective of Statistical Education and the Use of ICT

In the current Courses of Study, emphasis is placed on the enhancement of statistical education, and the theme of "analysis of data" as a study content in the statistical field requires students to understand the basic ideas of statistics and to be able to organize and analyze data and identify trends using these ideas. The content of the study is data scattering and data correlation.

In the practical example, a graph was created for the scatter of the data. They also created a scatter plot of the correlation of the data to grasp the trend. In junior high school, students learned how to capture trends in data through histograms and representative values under the theme of organizing data, and in high school, they handled more data. They had the experience of making predictions about the scatter of data and relationships among data, analyzing and verifying them, and finding further issues from them. In addition, they handled data from solar power installed at the school to deal with concrete data from their immediate surroundings. By using something familiar, students were more motivated to learn and could experience the benefits of using ICT. These were practical examples of enhancing statistical education emphasized in the current Courses of Study.

In addition, Excel, a computer spreadsheet software, was used as the tool for analysis. Students realized that data can be quickly processed using spreadsheet software. ICT is effective in data analysis, allowing them to instantly and visually capture the relationships among the data. This motivated students to further research to find new relationships using the data, and to formulate and verify hypotheses that setting new conditions might make a difference. Thus, using ICT was very effective in promoting the students' research. In addition, the students' future issues, such as the temperature of solar panels and power generation efficiency, could be further researched using new

measurement equipment. The relationship between the temperature of solar panels and changes in the irradiation angle of the panels could be mathematically modeled for use in ICT. Furthermore, it may be possible to develop this into cross-curricular content, such as physics and economics. Considering the above, this was a practical example that allowed students to realize the effectiveness of using ICT and will enhance the statistical education required in the future.

4. Future tasks

Using statistical analysis software other than Excel and the handling of various data also effectively enhances Problem Research and statistical education. We want to continue to practice using ICT and verify its educational effects.

Regarding enhancing statistical education, activities are required to process a large amount of data using ICT to grasp trends and solve or discover problems. It is also stated that dealing with familiar things for such data is necessary. In addition to Excel, there is R for statistical analysis software, which is a simple language to code and does not require variable declarations. Many libraries have been created on the web, so we can use complex methods simply by calling the libraries. Despite the algorithm's complexity, it can be written in just a few lines. In addition, information such as teaching materials can be obtained from the Statistics Bureau of the Ministry of Internal Affairs and Communications website. In this regard, along with the deployment of tablet terminals, many educational materials and tools related to statistics. The fact that data science is attracting attention is also significant. We want to make actual use of this information.

In addition, one textbook company has the following theme for problem-based learning on data analysis. The theme deals with a bird's body weight and wing area. The bird must obtain force from its wings to lift its body weight to fly. Let us investigate the relationship between birds and wing area using data from various birds. In this assignment, 29 types of birds are shown in a scatter plot with body weight on the horizontal axis and wing area on the vertical axis, and a box-and-whisker plot of body weight is also shown along the axes. The assignment in the textbook is to find outliers in body weight from the box-and-whisker plots of body weight. After removing the weight "outliers," the remaining data is used to create another scatterplot, from which the weight "outliers" are again removed, and another scatterplot is created. The correlation between body weight and wing area gradually becomes weaker. The question is, "How can this phenomenon be explained? We want to work on this kind of data as well.

Furthermore, the Japanese Ministry of Education, Culture, Sports, Science, and Technology stated that the ideal form of children's learning that we aim for is "individualized, optimal and collaborative learning that draws out the potential of all children. The basic idea regarding the use of ICT for building school education is that ICT is indispensable as a fundamental tool for school education and that it is necessary to change school education, solve various problems, and improve the quality of education through the optimal combination of existing practices and ICT The paper is based on the following principles.

Currently, students are using tablets as "stationery" daily. Students input and express their opinions and visualize them using the whiteboard function and exchange opinions in groups or as a whole class. Students input and calculate data using spreadsheet software and summarize and discuss the results. Teachers and students communicate with each other via tablet terminals, and students collaborate.

The use of ICT in mathematics education has two aspects. One uses ICT to support the development of mathematical content, such as graph and graphic drawing software, spreadsheet software, and programming languages, which are used to deepen mathematical thinking. The other is to use the software like a paper notebook, emphasizing a variety of output and expression.

It is also a future task to verify in what situations those two aspects can be used well and what educational effects can be achieved.

Acknowledgments

This paper is an introduction to the mathematical activities undertaken by the students under the author's guidance. The author wants to express my gratitude.

Appendix

*1 Problem Research is an activity that presents an answer to an issue with a rationale. Students set their assignments. Activities conducted by individuals or groups.

*2 Super Science High School (SSH) is a national project that has been implemented since 2002, with the Japan Science and Technology Agency (JST) as the primary implementing agency, with the objective of "conducting research and development focusing on science and mathematics education to foster future global human resources for science and technology. SSH is an epoch-making initiative in that it allows the promotion of science and technology human resource development in specific schools to begin at the secondary education level and was established as a symbolic project following the birth of the Ministry of Education, Culture, Sports, Science and Technology (MEXT) following the reorganization of central government ministries and agencies. The program was established as a symbolic project symbolizing the birth of the Ministry of Education, Culture, Sports, Science and Technology (MEXT) after central ministries and agencies.

*3 For the Courses of Study, we referred to the "English Translation of the Courses of Study for Junior High Schools (Provisional Translation)" posted on the website of the Ministry of Education, Culture, Sports, Science, and Technology (Retrieved July 30, 2023, https://www.mext.go.jp/a_menu/shotou/new-cs/youryou/eiyaku/1298356.htm).

*4 We translated some image diagrams into English based on p. 26 of Reference [3].

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