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Statistical Inquiry Process and the Use of ICT

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Abstract: *In Japan, standards have been established for curricular organization. The latest standards mention the enrichment of inquiry, statistical education, and active use of ICT. We focus on the enrichment of statistical education in inquiry and describe a case study of problem research, one of the educational activities in the SSH project (Super Science High School), a national project to promote science and mathematics education, and problem study in the required course "Mathematics I." Based on this discussion, we propose future directions for statistical education and the use of ICT. Based on this discussion, we propose the future direction of statistics education and the use of ICT.*

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. One educational activity that participates 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 the statistical inquiry process and propose future statistical education and the use of ICT.

2. The Objectives of Mathematics*[3] and Mathematical Activities in the Courses of Study

The objectives of the mathematics department in the Courses of Study are as follows.

> 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, find properties of quantities and figures and explore them in an integrated and developed manner, and express events concisely, clearly, and accurately using mathematical expressions.
(3) Cultivate an attitude of persistent thinking and applying 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 Courses of Study to date show that "mathematical activities" are of great significance in mathematics education in Japan. Furthermore, ICT is practical and currently indispensable in those activities.

"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. In the world of mathematics, the student 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.

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

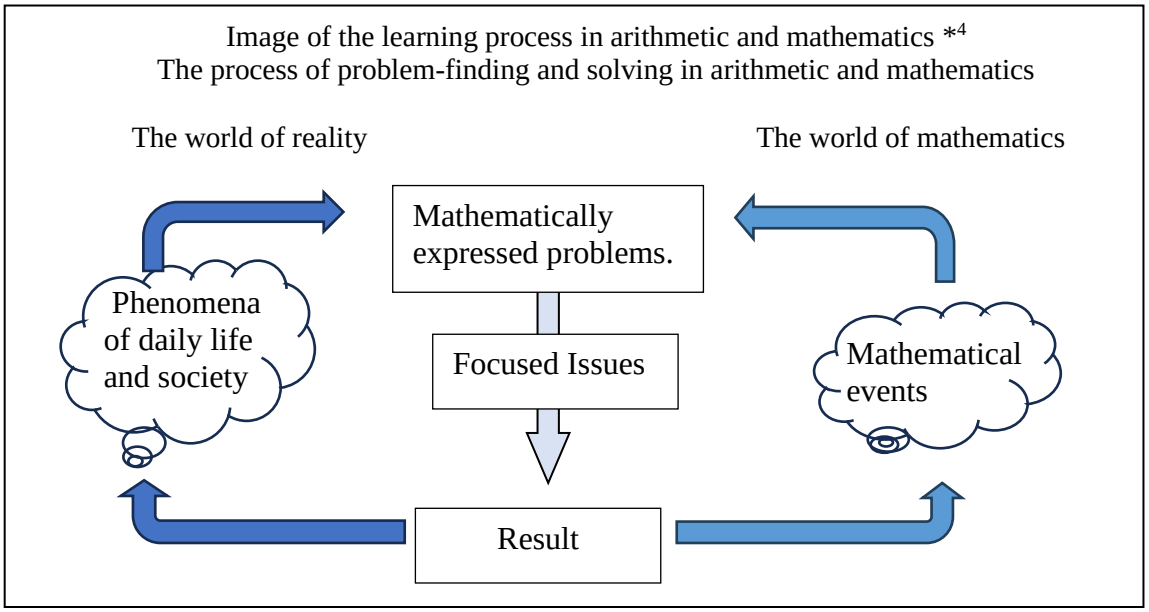

Figure 2.1 Image of the learning process in arithmetic and mathematics*[4]

3. Statistical Inquiry Process and ICT Application

3.1 Students' ICT Environment and Statistical Inquiry Process

Currently, each student is provided with a tablet device. A classroom support application has been installed in the author's prefecture. Each student is given a Google account, and the projector and screen are equipped in each classroom.

The statistical exploration process is a five-step process.

Problem	・Identification of the problem ・Issue setting
Plan	・Data assumptions ・Collection plan
Data	・Collection of data ・Organization into tables
Analysis	・Creation of graphs ・Identification of characteristics and trends
Conclusion	・Conclusion ・Reflection

The process consists of setting up a statistically solvable problem for the original awareness of the situation and what needs to be solved, considering the data to be collected and how to collect them for the set problem, actually collecting the data according to the plan, organizing the data into tables, summarizing the collected data into graphs according to the purpose and type of data, obtaining statistics, identifying characteristics and trends, summarizing and expressing conclusions about the problem from the traits and trends found, and finding further issues and points for improvement for the entire activity. The process is a series of processes to grasp the characteristics and trends of the collected data by summarizing them in graphs and obtaining statistics, etc., according to the purpose and type of data, to express a conclusion about the problem based on the characteristics and trends found, and to see further issues and points for improvement of the entire activity.

3.2 Scenes of ICT use in the statistical inquiry process Class Outline

The use of ICT in the statistical inquiry process is expected to facilitate more concrete imagery in identifying, identifying, and planning issues by recording and storing images and sounds in the steps of problem identification, problem formulation, and planning. In data collection and analysis, data can be obtained, recorded, organized, arranged into tables, and visualized by creating graphs. Students can also be used to summarize conclusions, reflect on, and express or communicate the results. In analyzing data, spreadsheet software such as Excel or R is effective, and in summarizing and describing data, presentation software or Jamboard can be a tool for organizing thoughts. In addition, data collection using the Internet and online conferencing systems may be effective in the inquiry process, such as receiving expert advice. Next, we will discuss examples of ICT applications.

4. Class of the Use of ICT

4.1.1 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 4.1 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 also made to grasp the trend and determine the annual change. There were differences depending on the season.

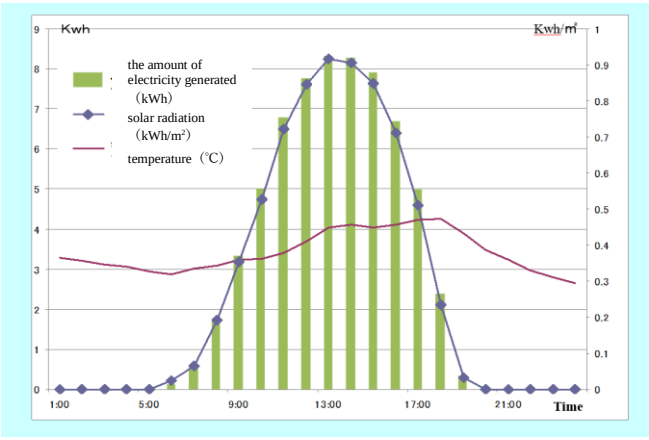

Figure 4.2 Graphs of the amount of electricity generated, solar radiation and temperature (sunny)

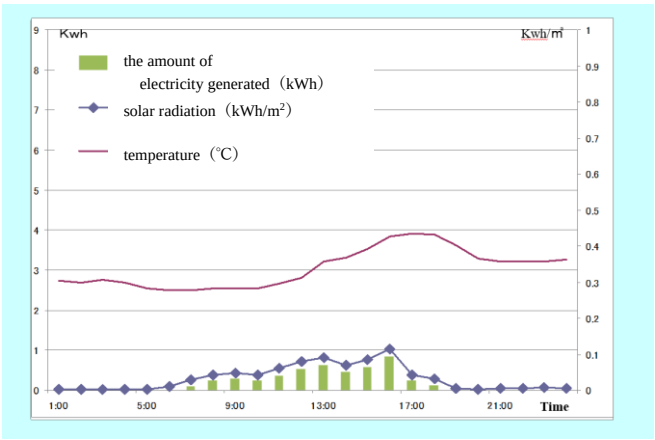

Figure 4.3 Graphs of the amount of electricity generated, solar radiation and temperature (rainy)

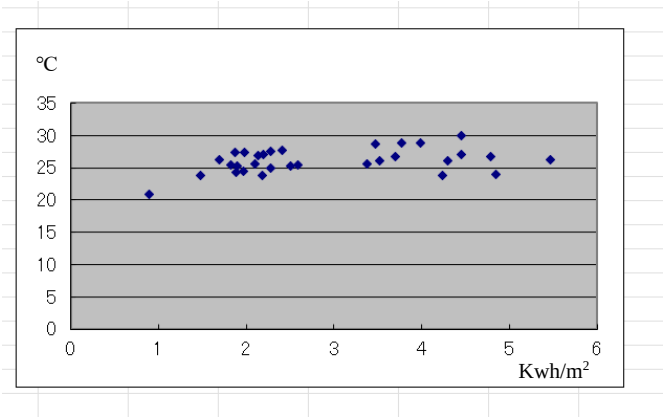

Figure 4.4 Scatter diagram of temperature and solar radiation

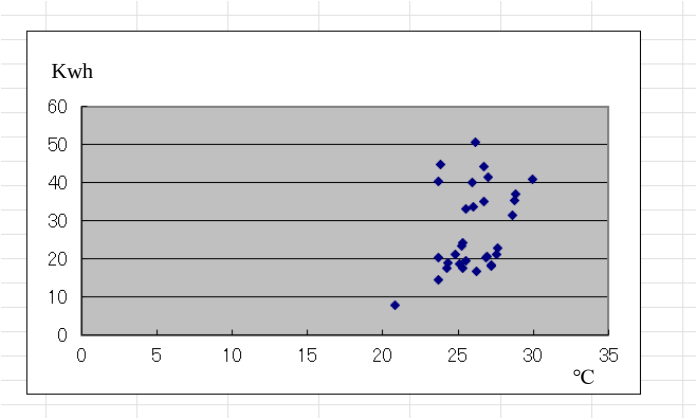

Figure 4.5 Scatter diagram of the amount of electricity generated and temperature

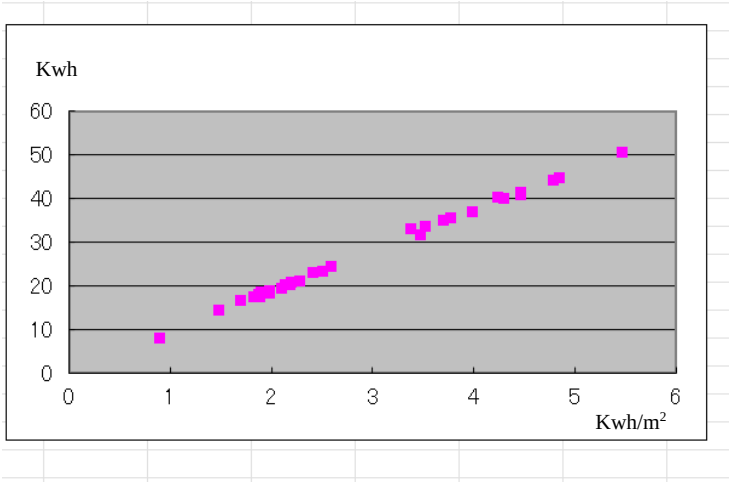

Figure 4.6 Scatter diagram of the amount of electricity generated and solar radiation

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])

Data analysis from the past five years shows that solar radiation and electricity production 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 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])

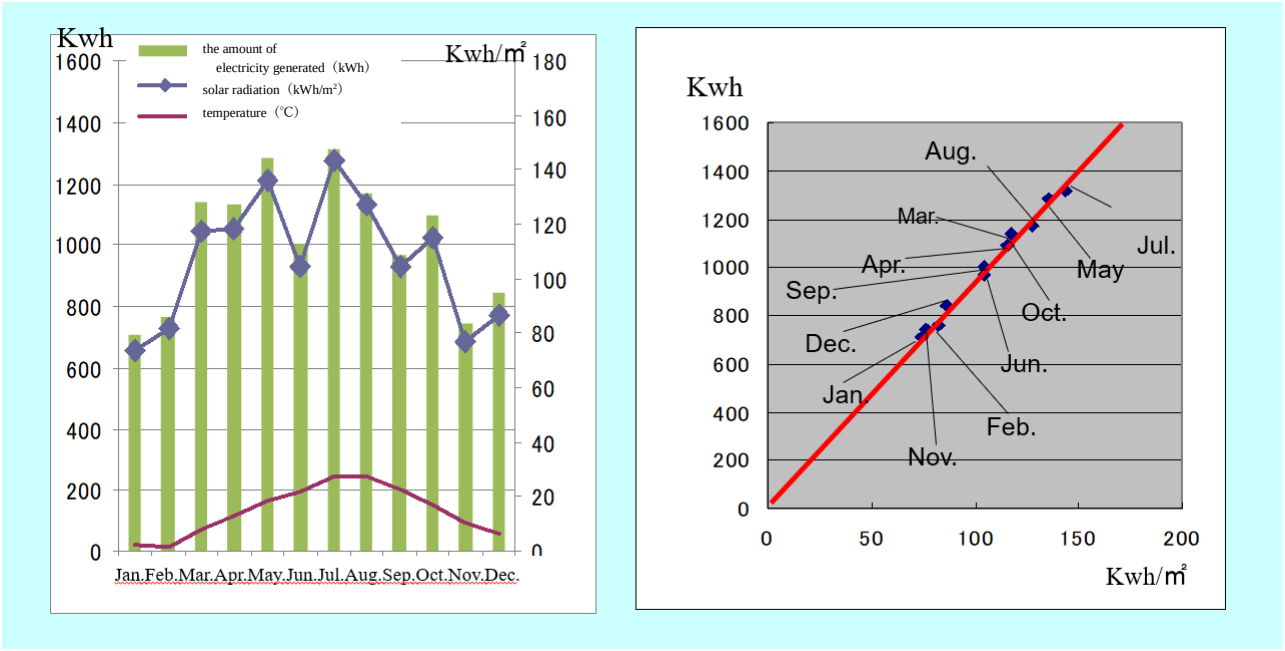

Figure 4.7 Graphs of the amount of electricity generated, solar radiation and temperature (year)

Figure 4.8 Scatter diagram of the amount of electricity generated and solar radiation (year)

For future development issues, Students said that they would like to research the relationship between solar panel temperature and power generation efficiency, the relationship between weather and power generation, and confirm 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.

4.1.2 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 provide 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 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.

4.1.3 The problem-based learning of "Mathematics I"

In Japan, Mathematics I is a required course. Required courses are courses that the school's curriculum must take high school students before graduation. The content of Mathematics I includes

numbers and expressions, figures and measurements, quadratic functions, data analysis, and problem-based learning. Problem-based learning encourages students' independent learning and helps them recognize the merits of mathematics by setting tasks that increase students' interest and motivation by relating or developing the content studied or interrelated content with their daily lives. In the Courses of Study, it is stated that the content of Problem-based learning should be implemented at appropriate times and in proper situations to increase the effectiveness of learning based on the relationship with each content, and mathematical activities should be further emphasized when implementing the content. The following is a summary of the contents of the program. The study tasks may be placed at the end of each unit or after every unit, with the latter being the case for content covering multiple fields. The former has the advantage of dealing with the subject immediately after the end of the unit, and the latter has the advantage of allowing students to feel the connection of mathematics.

The author and other research team members conducted a survey on how problem-based learning is described in all 17 Mathematics I textbooks (from five different companies), which the Department of Mathematics approves at upper secondary schools. As a result, they simultaneously investigated whether the problem-based learning in each of the Mathematics I textbooks focused on the world of everyday life and social phenomena or that of mathematics and categorized them as "mathematics" when they dealt with mathematical phenomena and "reality" when they dealt with everyday life and social phenomena.

The results of this survey were as follows.

1. Numbers and expressions (23, reality: 16, math: 7)
2. Quadratic functions (30, reality: 17, mathematics: 13)
3. Trigonometric ratios (25, reality: 13, mathematics: 12)
4. Sets and propositions (10, reality: 7, mathematics: 3)
5. Analysis of data (19, reality: 16, mathematics: 3)

Overall, of the 107 pieces, 73 were "reality "and 34 were "mathematics." In addition, 9 were arranged as content integrating multiple disciplines. Since this paper focuses on the statistical inquiry process, when looking at the field of data analysis, 16 out of 19 dealt with familiar themes.

The themes were as follows.

1. How can we effectively advertise based on the survey results?
2. Using data from national and regional surveys, look for local problems and develop solutions.
3. Analyze the relationship between points won and standings based on data from soccer match results.
4. Investigate the relationship between birds and wing area using data on various birds based on the bird body mass and wing area data.
5. Correlation coefficients from physical fitness data
6. Examine the relationship between winter and summer temperatures.
7. Inferring data from analyzed results.

In this section, we will address the bird body mass and wing area issue. For this assignment, 29 bird species are shown in a scatter plot with weight on the horizontal axis, wing area on the vertical axis, and a box-and-whisker plot of weight along the axis, as shown in the figure below (See [9]).

I created a study plan using this assignment with the following two-hour dividend.

Study Guidance Plan (2 hours dividend 50 minutes x 2 hours)

Hour 1

process	Study Contents and Activities	matters that require attention	Form of study
Introduction (5 minutes)	Confirm the issue currently.		simultaneous
	Data on body mass and wing area for 29 bird species are represented in scatter plots. Box-and-whisker plots were also shown for body mass and wing area, respectively. (See [9]) Consider the following assignment. 1. Let's find out how many grams more than the body mass outlier is from the box-and-whisker diagram of body mass. 2. Let's create a scatter plot again from the remaining data, excluding the outliers obtained in 1. Let's also show a box-and-whisker diagram of body mass and determine how many grams more than the weight outlier is. 3. Summarize the correlation coefficients for each data and summarize what can be said about the bird's weight and wing area from the results.		
		Data will be sent to individual student's terminals after assignment confirmation.	
Deployment (43 minutes)	Group together and work on issues.	The group will discuss and think about it.	Group (about four persons)
	Create scatter plots and box plots using spreadsheet software.	The obtained outlier values, scatter plots, and box plots will be reviewed with the entire class.	
	Calculate the zero-correlation coefficient.	Confirmation of how to obtain correlation coefficients. Assist students as you see fit.	
	Consider the change in the correlation coefficient.	Regarding the change in correlation coefficients, why does this phenomenon occur?	
	Share it with the entire.	How should outliers be handled? What are the criteria for outliers? What statistics are most susceptible to outliers? Conversely, what statistics are less vulnerable? Encourage consideration of data handling by asking questions such as the following.	

Summary (2 minutes)	Reflections on the class	Submit a Google form with your reflections on the current activities.	individual

Hour 2

process	Study Contents and Activities	matters that require attention	Form of study
Introduction (5 minutes)	Confirm the contents at the time before	Reflecting on the activities of the previous period	simultaneous
Deployment (40 minutes)	Understand the statistical exploration process.	Explain the statistical inquiry process, comparing it to the activities of the previous period.	simultaneous
	Using the data, let's set up a new issue and analyze it.		
	Set and analyze issues.	We are presenting new data. Assist them in finding more data, working with different data, and other exploration issues.	It should also be possible to discuss the issue in groups.
Summary (5 minutes)	Reflections on the class	Enter your reflections and the issues you set in the Google form and submit.	individual

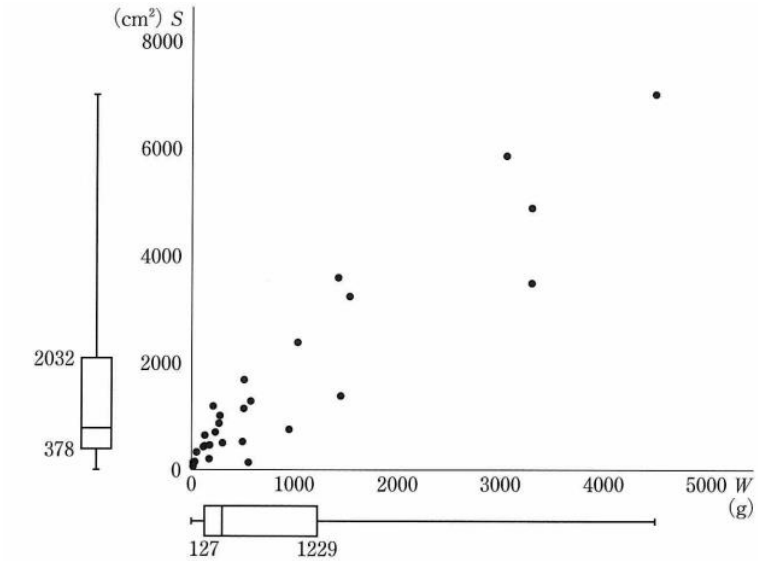

Figure 4.9 Boody mass and Wing area

The author found this issue very interesting and obtained the data[*5]. From that data, the author used 31 data to create scatter plots using Excel and R. The primary tool for analysis is Excel, a computer spreadsheet, but there is also R for statistical analysis software in addition to Excel. R is a simple language that does not require variable declarations, etc.; coding is simple, so it is easy to create. I felt that I would like to introduce it to my students. (See [10] and [11])

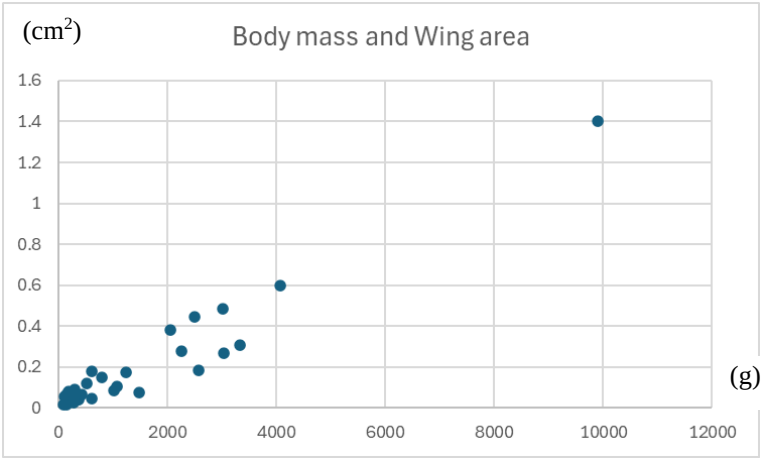

Figure 4.10 Scatter diagram created in Excel

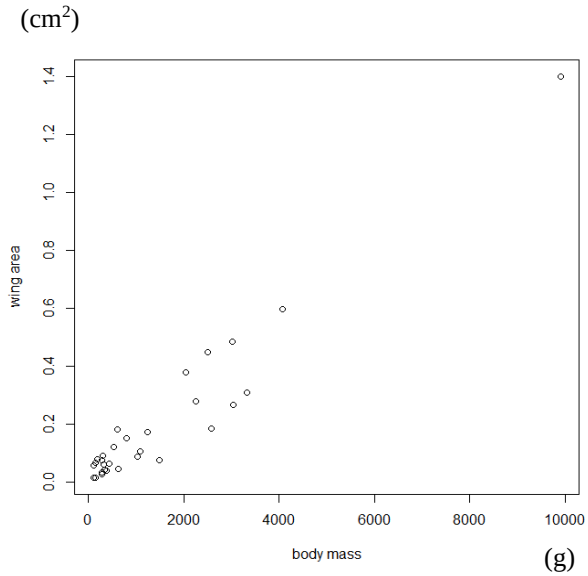

Figure 4.11 Scatter diagram created in R

From this data, students can calculate not only "body mass" and "wing area" but also the correlation coefficient between "body mass" and "wingspan" and between "body mass" and "wing area" for different birds living in southern and northern regions by themselves. By developing such activities, we believe that there is a possibility of developing biological exploration activities from data analysis about the ecology of regions and birds, as well as physical exploration activities from body mass and wing area. It is expected to develop into cross-curricular learning.

4.2 Consideration of Classroom Practice

In the current study guidelines emphasize the enhancement of statistical education. The theme of "analysis of data" as a study content in the statistical field requires students to understand the basic ideas of statistics, organize and analyze data, and identify trends using these ideas. The learning contents are data scattering and data correlation. Let us examine the lessons from the viewpoint of statistical education and ICT utilization.

Problem Research, described in Section 4.1.1, is a practical example in which the mathematical activities described in Chapter 2 of this paper can be practiced through a statistical exploration process. The students have learned to capture trends by creating graphs about the scattering of data and scatter plots about the correlation of data. In junior high school, students learned how to capture trends in data through histograms and representative values under the theme of organizing data, and they handled more data in senior high school. 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 a solar power generation system installed at the school to deal with concrete data from their immediate surroundings. By using something familiar, the students were more motivated to learn, and they were able to experience the benefits of using ICT. These were effective examples of enhancing statistical education emphasized in the current Courses of Study.

By using ICT to process a large amount of data, they were able to find relationships and confirm the results of previous studies to find out the characteristics of the area in which they live and future issues based on these characteristics. This is also an example of how the real world and the world of mathematics can be perceived as close to each other through analysis of data found in familiar places.

The author believes that ICT is effective in conducting research using data in this way, and Course, described in Section 4.1.2, is a case study aimed at developing a foundation for actively using ICT to use data.

Problem-based learning, described in Section 4.1.3, investigated the theme of problem study positioned as a summary in the "analysis of data" of the field of study related to statistics, which was emphasized in the revision of the Courses of Study and described one instructional example. Each theme deals with a problem close to the students' hearts, and the content allows students to collect multiple types of data according to their objectives, analyze them using statistical methods, and conduct activities to discuss the process and results of the solution. As in Problem Research, described in Section 4.1.1, students can use ICT to organize data into graphs and obtain basic statistics such as variance, standard deviation, and correlation coefficient. Based on these, the students can discuss the conclusions obtained while clarifying the rationale through questions from the teacher and dialogue within the group and develop them into the next exploration topic. They can also critically examine the data by considering the conditions of data collection, etc., or by increasing the number of data further. If a survey was conducted in an inquiry activity, students can use this experience to analyze the data. For example, students may be familiar with surveying and analyzing the time spent using smartphones.

5. Summary and Future tasks

The use of ICT is found to be effective in analyzing data in the statistical inquiry process. As students gain more experience in this process using ICT, they will be able to acquire methods for analyzing real-world problems in the real world in the future. In the problem-solving process, students will be able to review and modify the problem while planning, re-create and analyze graphs, and sometimes re-collect data to reach a conclusion.

This paper introduces examples of ICT applications around data analysis in problem-based research and problem-based learning in "Mathematics I," where exploratory activities are conducted. The theme of problem-based learning listed in the authorized textbooks is the theme of activities in which students use the scatter plots and correlation coefficients they have studied to formulate hypotheses about problem situations, collect data, and test their theories. As shown in the examples of the practical application of the problem study, after analyzing data and deepening consideration

of the hypothesis, students could discover new problems of which they were previously unaware and engage in activities to formulate hypotheses. These experiences also lead to exploring conditions and remedial measures to change from the current distribution of data to the direction considered desirable to solve further or improve the problem.

ICT has the advantage that representative statistics can be easily calculated and visualized for many data types. However, to use ICT to select appropriate statistics, graphs, and methods according to the purpose and type of data in the statistical exploration process, it is necessary to have a solid understanding of statistics such as mean, minimum, maximum, median, mode, range, and interquartile range, as well as bar graphs, line graphs, and scatter plots, It is also necessary to organize the purposes for which graphs, such as bar graphs, line graphs, histograms, box plots, and scatter plots, are often used for what kind of data and for what purposes. These are also important in enhancing statistical education and applying the learning to elementary, middle, and high schools.

On the other hand, in teaching statistical education, the Statistics Bureau of the Ministry of Internal Affairs and Communications website[*6] is a good reference for obtaining information such as data and teaching materials. Along with the deployment of tablet terminals, information on teaching materials and tools related to statistics has also become more common. Data science is also attracting a great deal of attention. The author also wants to utilize them and feels teachers must learn to use data and practice. For this purpose, training, research, and the accumulation of practical examples will become increasingly important in the future.

As for future issues, we would like to conduct further research on the enhancement of statistical education and the use of ICT. We would like to devise practical examples of ICT-enhanced classes on the concept of hypothesis testing, which leads to the content of statistical inference. We would also like to study examples of ICT-enhanced problem-based learning in Math II and Math III.

In this issue, we also discussed the use of ICT in the statistical inquiry process, which focuses on supporting the development of mathematical content such as graph and graphic drawing software, spreadsheet software, and programming languages to deepen mathematical thinking. Other uses of ICT are those focused on setting up problems, using it in the stages of summarizing and concluding, and diversifying summarizing, outputting, and expressing. It is also a future issue to verify what kind of things, how to use them, and what educational effects they can have.

Acknowledgments

This paper introduces the mathematical activities undertaken by the students under the author's guidance. The author would also like to thank all those who assisted in this research.

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 that symbolized 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].
*5 We thank Dr. Kozue Shiomi for providing data on bird weight, wing area, and wing opening length. We thank her very much. The details of the data can be found at the following URL: https://sites.google.com/view/wing-data/home (viewed on May 16, 2023)
*6 The Statistics Bureau of the Ministry of Internal Affairs and Communications website URL: https://www.stat.go.jp/teacher/index.htm (viewed on August 30, 2023).
*7 In the "Problem Study and ICT Use in Mathematics Education" presented at ATCM 2023, we have included a perspective from the statistical inquiry process, and the problem study proposed in the textbook section on enhancing statistical education. We also included a study guidance plan for teaching the class.
*8 The author would like to sincerely thank Dr. Wei-Chi Yang for allowing me to prepare such a paper.

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