INGENUITY AND CHALLENGES TO INCORPORATE STATISTICAL-INQUIRY PROCESS INTO STATISTICS LESSONS IN PRIMARY SCHOOLS: THE CASE OF JAPAN

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In the new Japanese curriculum of mathematics for primary and secondary schools, which will be implemented successively from 2020, statistics education has been strongly emphasized. One of the big targets of new statistics education in Japan is to incorporate statistical-inquiry process in usual lessons. This paper illustrates two Japanese lessons at primary level focusing on the statistical inquiry with different ways of collecting data: Firstly, a 3rd grade (aged 8–9) classroom using children's data in their daily life, and secondary, a 5th grade (aged 10–11) classroom using data obtained from experiments. Based on these cases, we discuss ingenuity and challenges to incorporate the statistical-inquiry process into statistics lessons in primary school, in order to derive practical implications for future statistics education in Japan.

BACKGROUND

In Japan, the new curriculum of mathematics for primary and secondary schools, which will be implemented successively from 2020, has been published in 2017 and 2018. Statistics education has been strongly emphasized in the curriculum based on the recognition of the power of statistics in today's information and knowledge-based society. Table 1 shows statistical contents at primary level in the previous and new Japanese Courses of Study (Ministry of Education, Culture, Sports, Science and Technology, 2008, 2017). In the table, the italic letters are contents newly incorporated into the new course of study.

Table 1. Statistical contents at primary level in previous and new Japanese Courses of Study

Grade (Age)	Previous Course of Study	New Course of Study
1th (aged 6-7)	・Pictograph	・Pictograph
2ed (aged 7-8)	・One-dimensional table ・Pictograph	・One-dimensional table ・Pictograph
3rd (aged 8-9)	・One-dimensional table with some groups ・Bar graph	・One-dimensional table with some groups ・Bar graph
4th (aged 9-10)	・Line graph ・Two-dimensional table	・Line graph ・Two-dimensional table
5th (aged 10-11)	・Pie/Column graph	・Pie/Column graph ・Average of measured values ・*Way of statistical problem solving* ・*Critical thinking*
6th (aged 11-12)	・Mean ・Frequency distribution table ・Histogram ・Possible cases	・*Representative values (mean, median, & mode)* ・*Dot plot* ・Frequency distribution table ・Histogram ・*Way of statistical problem solving* ・*Critical thinking* ・Possible cases

Note. Newly incorporated contents are shown in italics.

In M. A. Sorto, A. White, & L. Guyot (Eds.), *Looking back, looking forward. Proceedings of the Tenth International Conference on Teaching Statistics (ICOTS10, July, 2018), Kyoto, Japan.* Voorburg, The Netherlands: International Statistical Institute. iase-web.org

There are two big targets of new statistics education at primary level in Japan. The first target is to integrate the statistical-inquiry process and the PPDAC (*problem*, *plan*, *data*, *analysis*, and *conclusion*) cycle (e.g., Wild & Pfannkuch, 1999) into usual statistics lessons. In the new curriculum, the statistical-inquiry process and the PPDAC cycle are represented as ‘statistical problem solving’. In the 5th and 6th grades, knowing a way of statistical problem solving is stipulated (Table 1). Children are encouraged to appreciate statistical problem solving and to promote statistical problem solving by themselves as much as possible. Although there is no mention of knowing what is statistical problem in other grades, teaching oriented statistical problem solving is emphasized from the 1th grade. The second target is to emphasize critical thinking (e.g., Wild & Pfannkuch, 1999; OECD, 2003) in statistical inquiry from upper grades. In the 5th and 6th grades, fostering critical thinking is stipulated (Table 1). Children are encouraged to not only discuss critically statistical information produced by others, but also look back on their own statistical-inquiry process and the validity of conclusions drawn by themselves. These changes are a big shift and issue for Japanese primary school teachers because of two reasons: (1) teaching statistics in primary school in Japan has mainly focused on calculating statistics and writing and reading statistical graphs, and (2) almost of all teachers do not have any experiences of statistical inquiry, hence they do not know what is statistical-inquiry process and how to integrate the process in the usual teaching of statistics. We address the latter, discuss ingenuity and challenges to incorporate the statistical-inquiry process into statistics lessons at primary level from two advanced cases in Japan, and derive practical implications for future statistics education in Japan.

JAPANESE−LESSON CASES INCORPORATING STATISTICAL−INQUIRY PROCESS

We introduce two Japanese-lesson cases that incorporated statistical inquiry with different ways of collecting data: Firstly, a 3rd grade (aged 8–9) classroom using children’s data in their daily life, and secondary, a 5th grade (aged 10–11) classroom using data obtained from experiments. In each case, we show the lesson details along with the phases of the PPDAC cycle.

Lesson case 1: Statistical inquiry using children’s data in their daily life

First lesson case was designed according to the statistical-inquiry process (for the lesson details, see also Aoyama & Ono, 2016) using children’s data in a 3rd grade (aged 8–9) classroom in Japan. The lesson theme is ‘*How to decrease to forget something in our class*’. The reason of deciding the theme is why many children in this class tended to forget homework, stationery, and something. The teacher demonstrated the contents of *problem*, *plan*, and *data* phases that he had implemented before class and the children carried out the *analysis* and *conclusion* phases.

In the *problem* phase, the teacher decided what to focus on the theme before class. The following problem was formulated and demonstrated to the children: ‘*Let’s make sure the differences of life style between children who don’t forget anything and forget many things*’. Of course there were many choices of the problems at this stage, but an open statistical problem was too difficult for the children. So the teacher decided the somewhat formalized problem.

In the *plan* phase, the teacher considered the subject, sample size, and questionnaire items before class. The number of children in the class was 31 and this class was only one classroom in the 3rd grade in this school. The teacher needed more data from other grades or schools and wanted to give the data from same grade groups. So he collected 3rd graders’ data from two next schools. Some of the questionnaire items he used were followings:

A) Do you forget anything many times?
B) When do you usually do your homework?
C) When do you prepare next school goods?
D) How long do you play TV game or watch TV program in one day?
E) What time do you sleep?
F) How long to talk with your family?
G) Do you have any animals? (Total 12items)

Questionnaire items A is core of the theme, and B, C, D, and E are related to the theme because they reflect children’s life style. And items F and G are not related directly to the theme but can extend the children’s activity of analysis.

Before the *analysis* phase, the teacher overviewed the data and chose the items given to the children, because 12 items were too many for the children. He chose items A, D, E, and G for the children. Some relationships were showed from those items. He made the *Data Card* on which the individual data were printed (Figure 1). In the lesson, the teacher distributed one set of the Data Cards to each group of the children. Bar graphs (Figure 2) are the result of children's data for the items.

forget things many	TV Game some
sleep nine to ten	animals dog

Figure 1. Data Card with four items

Figure 2. Bar graphs with four items

In the *analysis* phase, the children found that there were differences between 'don't forget' and 'forget many things' children who slept after 10 o'clock or spent long time with TV program or TV game. This result reflected a tendency of children's life style and to forget somethings. Interestingly, the 'House animals and forget something' graph showed that no children who 'don't forget' had a dog or a cat. The children who had a dog or a cat in their house usually forgot somethings. The teacher and children were strongly surprised at the result and wondering why such tendency we got. The children were able to think about the result critically (e.g. 'Dogs or cats are not cause of forgetting'). They thought that some other causes would exist between these two phenomena.

In the *conclusion* phase, the children concluded based on the result of analysis (e.g. 'We need to be careful not to stay up late or to watch TV long time, especially before finishing our homework').

In this lesson case, it was too difficult for 3rd grades to set up the problem and plan to gather data, the teacher guided these phases mainly and demonstrated those parts to the children. We need to consider from which grades and how children can carry out statistical inquiry by themselves. The data using in this lesson were connected with children's daily life and the results of analysis were interesting. Such kind of open and interesting experience of analysis can give children motivations and learning fun.

Lesson case 2: Statistical inquiry using data obtained from experiments

We illustrate another lesson case (for the lesson details, see also Kawakami, 2013, 2017) that included statistical inquiry using experiments from a 5th grade (aged 10–11) classroom in Japan. This lesson aimed to form children's aggregate views of data distribution through conjecturing and validation. Throughout the lesson, the children were asked to engage in the *Paper Helicopter Experiment* (*PHE*) as shown in Figure 3. The PHE focuses on measuring the flight times of paper helicopters dropped from a certain height. The simple experiment is easy for children to imagine the cause of the variation (Kawakami, 2017). Hence, it has been adopted in primary and secondary statistics education (e.g. Ainley et al., 2000; Doerr et al., 2017; Kawakami, 2013; Okamoto et al., 2016). This lesson case focused on the following opportunities through the PHE: to (a) statistically explore changing conditions of the experiment and (b) form and validate conjectures about flight-time distribution as informal statistical inference (e.g. Makar & Rubin, 2009), in order to compare the helicopters with different blades. We focus on the former (for the latter refer to Kawakami, 2017).

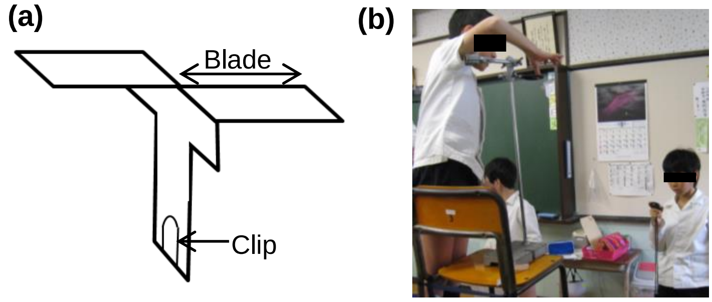

Figure 3. (a) The paper helicopter (b) Child dropping a helicopter and child measuring its flight time with a stopwatch

In this lesson case, although the entire PPDAC cycles were incorporated, the *problem* phase was demonstrated to some extent by the teacher in consideration of the primary level and time consuming. However, the lesson case was designed to allow the children to grasp the statistical problems and to have purpose consciousness through experiments. For the remaining phases of *plan*, *data*, *analysis,* and *conclusion*, the teacher guaranteed the time for the children to think and discuss by themselves. We focus on the second round cycle.

In the *problem* phase, the teacher illustrated new problem while taking advantage of the children's critical consideration against an initial problem. The initial problem was '*Compare the helicopter with 5-cm blades and 10-cm blades. Which do you think will have a longer flight time?*' For this problem, the children performed the first experiment, collected two data sets of flight times, and arranged them in dot plots. Data were converted into 0.01 bps for easier data management. Although the children drew a conclusion by calculating the mean of the flight times, they critically considered the conclusion due to many variations in the first experiment's results:

C1: The result will change depending on how to make the helicopter, so we cannot say which is longer.
C2: The helicopter with 10-cm blade fell as soon as it hit the desk. Because its wings were long.
C3: Extreme values may indicate that.

The children's consciousness of variation through experiments created a critical consideration towards previous conclusion, which led to the setting of new problem: '*What can you do to reduce the variation of the data?*'

In the *plan* phase, the children conjectured what would influence the data variation, discussed ways to improve the initial experiment and drew sketches of a distribution of either helicopter's flight time. The children conjectured the following sources of variation: 'difference in the length of dropping', 'accurate use of the stopwatch', and 'angle of blades', correlating the sources and contexts to values in the dot plot as shown in Figure 4, and they summarised improvements of experiment: 'aligning drop height', 'keeping blades parallel', and 'aligning the timing of stopwatches'. They conjectured 'mountain-like distribution', 'tower-like distribution, and 'castle-like distribution'.

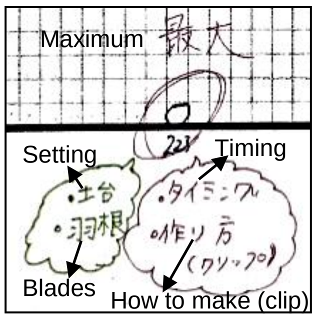

Figure 4. Value and context

In the *data* and *analysis* phases, the children conducted the second experiment, arranged two data sets of flight time in dot plots and verified their initial conjectures (source and result) by comparing with the real distribution. The children focused on the concentration of data and called it the 'clump area', as shown in Figure 5. In addition, they connected the 'clump area' and the mean.

In the *conclusion* phase, the children decided whether the variation of the second experimental result was reduced as compared with the first experimental result. They noted that data variations of both paper helicopters were reduced based on the dot plots as shown in Figure 5 (e.g. 'There are clump areas', 'The values are gathered around the mean', and 'The range is smaller'). They concluded that improvement measures of experiment decided by classmates were meaningful. Some children grasped the conclusion critically because of the existence of artificial variation (e.g. 'Any improvement cannot be perfect').

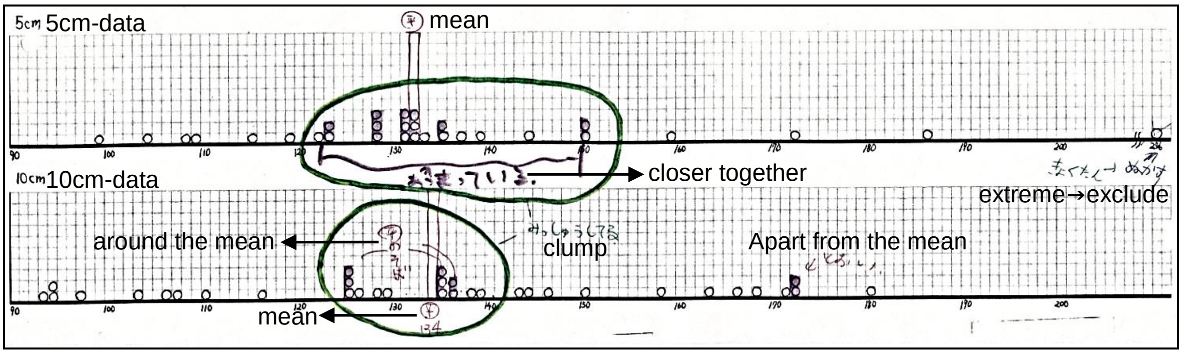

Figure 5. Sample of flight time data of 5-cm and 10-cm bladed helicopters in the second experiment (5-cm blades: n = 30; 10-cm blades: n = 34)

After the statistical-inquiry cycle, the children tackled again the initial problem: '*Compare the helicopter with 5-cm blades and 10-cm blades. Which do you think will have a longer flight time?*' Based on the result of the second experiment, they compared the results with a multifaceted viewpoint in association with the mean and clump area (e.g. 'comparing the mean excluding outliers'). In addition, the teacher looked back on the process of solving the problem and organized important matters in statistical problem solving with the children (e.g. 'You can make better judgment by comparing distributions from various perspectives such as mean, spread and clump areas', 'In order to reduce the variation of data, it is important to repeat experiments considering cause and remedy'). The children acquired knowledge of a way of statistical problem solving (Table 1).

DISCUSSION AND IMPLICATIONS

From two lesson cases, we draw ingenuity and challenges to incorporate statistical-inquiry process into statistical lesson practices in primary schools, in order to derive practical implications for future statistics education in Japan. We can find two ideas to incorporate the statistical-inquiry process into statistics lessons at primary level: (1) using data related to children themselves (i.e. data about children and data children collected), (2) entrusting and guiding statistical inquiry according to children's ability and time constraint.

Regarding the first idea, both lesson cases used data that children themselves produced, but with different ways of collecting data. In the lesson case 1, data of same graders including the children's data were used, although the teacher collected the data through questionnaires. Children's data related to their life (i.e. Data of lost articles) encouraged the children's understanding of the problem and facilitated their purpose consciousness of inquiry and sense making of data and results, leading to their attitude to pursue the factors behind the data. In the lesson case 2, the children collected data through experiments. Authentic data in experiments encouraged them to become aware of data variation (e.g. outliers) and its source as shown in Figure 4. Ben-Zvi et al. (2018) also identified the provision of real, or realistic, and motivating data sets as design dimensions for statistics learning environment. Providing rich data is essential for children to pose various questions and engage in statistical inquiry with real feeling.

As for the second idea, it is often pointed out that complete investigations from posing a question through drawing a conclusion will be very time-consuming and challenging for children (Watson et al., 2018). In the lesson case 1, the teacher demonstrated the context in the *problem*, *plan*, and *data* phases, the children did not carry out these phases by themselves. In the lesson case 2, the teacher shared purpose consciousness with the children and they carried out from the *plan* to *conclusion* phases successively by using experimental activity that included conjecturing and validation. Experimental activity also facilitated the development of children's statistical ideas about variation and distribution (Kawakami, 2017). Using experimental activity can be an approach to incorporate small statistical-inquiry process into statistical lesson practices in primary schools. In addition, critical thinking made a trigger to advance children's statistical inquiry in both cases. Drawing critical thinking, emphasized in future statistics education in Japan (see Table 1), can help children anticipate further inquiry even if children don't carry out it. Thus teachers need to demonstrate the context of a series of statistical-inquiry process to children and share the context and purpose consciousness with them when focusing on the specific phases of statistical inquiry.

We can also find two issues to implement the statistical inquiry in statistics lessons at primary level: (1) How to support children's inquiry that gone away in an unexpected direction, and (2) How to use raw data and existing data properly. Regarding the first issue, in the lesson case 1, using multi-variate data realized open and interesting activity of analysis. When preparing lessons, teachers themselves need to experience statistical inquiry and identify the feathers of data to be handled as much as possible. In the lessons incorporating statistical inquiry, it is also important for teachers to clarify the aim of statistics lessons (e.g. emphasising 'statistical inquiry as content' to engage children in statistical investigation itself or 'statistical inquiry as vehicle' to construct statistical concepts). As for the second issue, the lesson case 2 tried to focus on intended statistical ideas by using raw data. The teacher accepted to repeat experiments to reduce variation and clarify distribution trend more. However, it took time to repeat the experiments. Even if the experiment is repeated, it is not always possible to obtain data that is easy to grasp the distribution tendency. If teachers want to focus on constructing statistical ideas and concepts through statistical inquiry, they may consider using existing data as pointed out by previous research (e.g. Ben-Zvi et al., 2018).

In future statistics education in Japan, particularly at elementary level, implementing statistical inquiry is expected to be challenging for teachers. We need to find more ingenuity and challenges to incorporate statistical-inquiry process into statistics lessons through practical study and convey and share them in pre-service and in-service teacher training in Japan.

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