Research on learning to improve scientific inquiry skills and cultivate scientific wisdom

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Abstract

The Japanese government's 6th Basic Plan for Science, Technology and Innovation (2021) [1] points out that in this unpredictable age, it is important to have the skills to see things from multiple perspectives and solve problems. The report points out the necessity of further activating the "utilization of knowledge," such as promoting STEAM education. Japan's science education is one of the best in the world in "acquisition of knowledge", but there are many issues in "utilization of knowledge"[2]. ByBee argues that it is difficult to "apply knowledge" by simply learning the basics of science and mathematics, and that it is necessary to give students experience in applying knowledge and skills [3]. In Japanese school education, the new Courses of Study starting in the 2020 school year emphasize inquiry in all school types, especially in upper secondary schools, and include the introduction of "Period for Inquiry-Based Cross-Disciplinary Study," a new course for scientific inquiry, and "Inquiry-Based Study. In particular, "Period for Inquiry-Based Cross-Disciplinary Study" and "Inquiry-Based Study of Science and Mathematics" have been introduced in high schools. In this study, we aimed to cultivate the required "scientific wisdom" and improve scientific inquiry skills by "using knowledge" through scientific inquiry.

Keywords: *scientific inquiry, STEAM education, scientific wisdom*

1. Background of the study

In science education as it is currently practiced in Japan, excellent practices and research have been developed for "acquisition of knowledge", and it has been reported that Japan has always maintained a high level in international academic achievement surveys. On the other hand, the "application of knowledge," which should be emphasized, is currently left to the abilities of individual learners.
The stages of inquiry are classified into several categories, from setting the problem to writing the report, but there is no known method for steadily accomplishing each stage. However, there is no known method for steadily accomplishing each of these stages. The only known method is a standardized sentence,"*teikei bun*" (Matsubara, 2001)[6] in the report writing stage. This is the "basic model" of evidence-based thinking, which is a formula made up of only the essential elements for judgment. Since the achievement of all stages of inquiry is meaningful, we decided to apply the concept of "*teikei*" to create a "basic pattern" as a means to support the achievement of each stage of inquiry, and to develop teaching materials and teaching methods that utilize the pattern.

2. Purpose of the study

The purpose of this study is to examine curriculum development and evaluation methods that aim to cultivate the required "scientific wisdom" and improve scientific inquiry skills through the "utilization of knowledge" through scientific inquiry using the "basic pattern".

3. Basic idea of the research

The scientific "ability to use knowledge and thereby cope with 'problematic situations'" (Seo, 2009)[6] is defined as "scientific wisdom". Awareness, which is regarded as a manifestation of scientific wisdom, is necessary to drive inquiry. The concept of this study is a cycle in which the accomplishment of inquiry leads to the acquisition of verification data and the improvement of inquiry skills, the data provides a basis for evidence-based thinking in the wisdom of science, and the absorbed knowledge becomes the wisdom of science, leading to awareness. For this purpose, we believe that a "basic pattern" for each learning process is necessary. The "basic pattern" is a method to support the accomplishment of inquiry by applying and developing the concept of "teikei" of fixed form instruction (Matsubara, 2001), which was clearly effective in describing results and discussions in report writing.

4. Framework of the Research Approach

To examine the process of inquiry, we focused on the NGSS framework [7]. It is composed of three pillars: 1) practices, 2) cross-disciplinary concepts, and 3) core ideas. It advocates practices as an inseparable part of knowledge and skills, and distinguishes between two types of practices (scientific and engineering practices) (left column in Table 1). The practices of the components have much in common, indicating the close relationship between scientific inquiry and engineering design practices. Both are truly inquiry activities. The Framework questions the so-called learning by tracing the process of inquiry, but in addition to the significance and value of inquiry, it points out the importance of criticism, which has not been focused on in the past. There is no mention of criticism in the elemental practices.

5. Comparison between the NGSS framework and this research group

The contents of the "basic types" A through F, which are the main focus of this study, are shown in contrast to the practices 1 through 8 above (Table 1).

Table 1 Science and engineering practices of the NGSS and specific research methods used by this research group

<table>
<tr><th>Scientific Practices</th><th>Engineering Practices</th><th>Specific research methods by this research grou</th></tr>
<tr><td>1 Asking questions</td><td>1 Defining problems</td><td>A. Organizing problems and tasks, identifying tasks, and selecting key concepts (Goto et al., 2020)</td></tr>
<tr><td colspan="2">2. Developing and using models</td><td>B Building a (scientific) model that uses formulas, and building a task accomplishment model (Teratani et al., 2020)</td></tr>
<tr><td colspan="2">3. Planning and carrying out investigations</td><td rowspan="3">C Experimental Design Template (EDT) (Teratani et al., 2019)</td></tr>
<tr><td colspan="2">4. Analyzing and interpreting data</td></tr>
<tr><td colspan="2">5. Using mathematics and computational thinking
6. (for science) and (for engineering)</td></tr>
<tr><td>6 Constructing explanations</td><td>6 Designing solutions</td><td rowspan="2">D Standardized text instruction (Matsubara et al., 2001)</td></tr>
<tr><td colspan="2">7. Engaging in argument from evidence</td></tr>
<tr><td colspan="2">8. Obtaining, evaluating, and communicating information</td><td>E Learning history sheet (Hori, 2006)
F Learning activities using mutual evaluation sheet (Goto et al., 2015)</td></tr>
</table>

In this paper, for reasons of space and discussion, only F is presented.
F <Criticism and Evaluation>: "8 Obtain, evaluate, and communicate information.
Use "F. peer assessment of learning activities using the mutual evaluation sheet. Based on the theory of "Assessment as Learning" (L.M. Earl, 2003) [8], this method incorporates peer assessment activities into learning activities.

6. Example of practical research on block materials using learning activities using the mutual evaluation sheet

As mentioned above, we are promoting research using the "basic types" for each of the processes shown in Table 1. In this section, we will discuss "learning activities using the F mutual evaluation sheet," which is an initiative that shows the total learning process for improving scientific inquiry skills and cultivating scientific wisdom.

6.1 Purpose of learning

The purpose of this course is to understand and share the "basic pattern" in peer assessment activities and the "basic pattern" when expressing records by conducting peer assessment activities.

6.2 Method

Through the creation of works in blocks and their recording, students will learn about the diversity of expression and recording, and will conduct mutual evaluation using the expressed records. After the peer assessment activities and the assessment activities, the students will share what is a record that can be conveyed to others, and what elements are necessary in a record, i.e., elements (viewpoints) of evaluation. The specific method is shown below.

(1) Using 10 pieces of commercially available blocks, freely create a work of art (in this practice, the theme was "living things").

(2) Describe the record of the work in (1) freely on a sheet of 5mm graph paper with the goal of "recording in a way that others can understand".

(3) [Verifiable evidence] Take a picture of the blocks in (2).

3) [Verifiable evidence] Take a picture of the blocks in (2).

(4) [Peer assessment activities (1)] Break the blocks into pieces and make them again as if they were others. Leave comments on what was good and what could be improved. They should also record the number of minutes it took them to complete it.

(5) [Peer assessment activity (2)] Disassemble the blocks again and have others make them. Leave comments on what was good and what could be improved. Leave comments on what was good and what could be improved, and record how many minutes it took to complete.

In each group, mutually discuss the good points and areas for improvement, and summarize three to four points about what kind of record can be conveyed to others.

6.3 Results and discussion

(1) Learners created their own original works, and all of them completed them in about 5 to 6 minutes.

(2) The learners used various expressions and took about 15 minutes to finish.

※Only one learner gave an explanation entirely in writing, without using diagrams. In the past, about one out of every 40 learners has given a written explanation without using diagrams.

(3) All the students had a photo function on their cell phones, and they used it to record the pictures.

(4) All learners were able to reproduce the block based on the record in about 2 minutes.

(5) It was decided to judge whether they could reproduce the block or not within 3 minutes. The factors that determine whether or not a block can be reproduced depend mainly on the creator's factors (the shape of the created block and the quality of the written record) and on the factors of others who are trying to reproduce it (their ability to read the record).

※It took more time or was not possible to recreate the blocks when they tried to recreate them by looking at others' records than when they tried to recreate them using their own records.

(6) The students were given about five minutes to discuss, and each group extracted about three to four elements.

(7) There were various elements necessary for recording from each group, but the elements necessary for recording were roughly categorized as "overall diagram, diagram of parts," "procedure," and "supplementary explanation (text, color, etc.).

Both the expressions in the creation and the recording are different for each person, but through the efforts using peer assessment and discussion, we realized that the necessary elements for recording can be summarized into about three.

7. Conclusion

In this report, as an example of the " mutual evaluation " approach, we learned the "basic pattern" in peer assessment activities about the elements necessary for expression related to scientific inquiry and the "wisdom of science" through the study of "block materials," and furthermore, we were able to understand, share, and deepen our thoughts about the "basic pattern" in recording and expression.

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