

Issues Concerning Scientific Processes in Science Lessons Involving Outdoor and Indoor Activities : A Comparative Study of Scientific Processes in Japanese Science Classes and the Chronological Development of Scientific Processes in the US through NGSS

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## Issues Concerning Scientific Processes in Science Lessons Involving Outdoor and Indoor Activities: A Comparative Study of Scientific Processes in Japanese Science Classes and the Chronological Development of Scientific Processes in the US through NGSS

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### Abstract

This study examined scientific processes in the science portion of the Course of Study of Japan. Also, a comparative study of scientific processes in the US and Japan was conducted among Japanese models, BSCS models, Yager's model, NGSS models, and other models. In particular, the study focused on the W-type problem-solving model developed in 2009 in comparison with other models. Results suggest that when science lessons approximate the activities of scientists, the W-type problem solving model is one of the most appropriate model. Long-term scientific inquiry by students can also be conducted using the W-type problem-solving model. However, we should develop simpler models such as the US models in everyday science lessons. Thus, the W-type problem-solving model describes important issues for the revision of Japan's Course of Study in the next framework.

### 1. Introduction

This study not only reveals that Japanese elementary and middle school science curricula are strongly affected by the scientific literacy developed in OECD/PISA studies, but also reviews scientific processes in science education, especially in the US, focusing on the history of BSCS in terms of scientific processes (2006) and the National Science Education Standards published in December, 1995. Furthermore, the NGSS (Next Generation Science Standards) developed in April 2013 specify new frameworks and models in all areas of science and engineering. In this paper, up-to-date models of scientific processes are discussed through a comparison of how science has been taught according to core documents of two countries. Also, we investigate the emerging needs of STEM (science, technology, engineering and mathematics) education, and compare these with the new W-shaped model recently developed by Goto and Kobayashi (2009). Our principal purpose is to clarify the scientific process model for future settings.

### 2. Methods

This study conducted in the following way. First, an analysis was conducted of website

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and journal papers published from 2006 to 2014. Second, an interview examination was developed in the US from September to December 2012, supported by the Fulbright Researcher Project and Grants-in-Aid for Scientific Research (B), No. 23300283. Third, a questionnaire was administered to undergraduate second-year university students.

We conducted qualitative research on 80 undergraduate students of a science education methods course in December 2013 and 2014. The students were all second-year students preparing to become science teachers at the middle- or high-school level. They were all Japanese students in the faculty of education, Shizuoka University. They were instructed to compare traditional and modern models of natural science translated into Japanese (Palmquist, et al., 1997). Also, they were asked to compare NSTA position statements on natural science. However, the students were not told which was right or wrong. They were asked to identify the W-type problem-solving model developed by Goto and Kobayashi (2009). In the questionnaire, three variables in the development of clouds were presented, and students were asked to design scientific hypotheses in order to develop experiments to find scientific evidence for cloud formation. The main portion of the questionnaire asked respondents whether their hypothesis was the same as that developed by scientists.

### 3. Outcomes

#### 3.1 Japanese Contexts

The current Course of Study has been greatly influenced by the definition of scientific literacy and the results of OECD/PISA, as shown in Figure 1. By examining scientific literacy as defined by PISA focusing on the processes of science, we can clearly see that learning about natural science is very important, in addition to an understanding of individual concepts from all areas of science and technology. Also according to PISA, an understanding of science and technology among not only the scientists and engineers but also non-experts is essential.

Furthermore, there are three major components of scientific literacy, namely, the ability to pose scientific questions, the ability to explain phenomena scientifically, and the ability use scientific evidence.

When we analyzed these processes in the Course of Study for elementary schools in Japan, we found that “to investigate natural phenomena by comparing” was addressed in the third year, “to understand natural phenomena by relating them to various variables in nature” was addressed in the fourth, and “to investigate natural phenomena related to various factors,” as well as “to carry out scientific processes in terms of regularities” were addressed in the fifth year. Also, processes of science “to understand the rules or characteristics of natural phenomena by inferring causes or regularities, or by predicting relationships” were found in the sixth year.

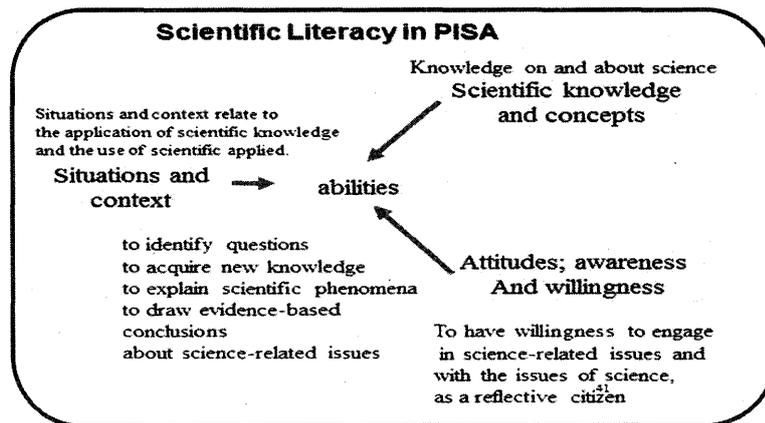


Figure 1. Scientific Literacy in PISA of 2006 (Summarized by Kumano)

In junior high school, scientific processes do not break down by year. Instead, it was found that “to cultivate scientific perspectives and scientific ways of thinking,” and “to analyze and to interpret results” were addressed in all middle school years. Basically, the teaching of junior high school science begins to approximate the inquiry of scientists. As a result, it becomes more difficult to break the curriculum into several pieces from the perspective of scientific processes when science lessons are conducted.

In high school science classes, inquiry activities are strongly recommended in all sciences when conducting scientific experiments, and the new subject rika kadaikenkyu indicates that scientific research has developed.

Based on the W-type problem-solving model (Figure2), which was originally developed in Japan as an anthropological exploration model, Goto and Kobayashi developed five detailed models. These five models seem similar to the NSTA position statement that there is no one exact approach in scientific processes. This model was especially developed for scientific field work. Also, this model is divided into two areas: thinking level and experience level. However, the W-type problem-solving model can also be identified as a basic model for science education, including question posing, data collection, observation, sorting and arranging, summarizing, integrating, developing hypotheses, planning of observations and experiments, setting tools for observations and experiments, carrying out observations and experiments, processing data, collating results, inquiring, making generalizations, and making applications to everyday life (Figure 2).

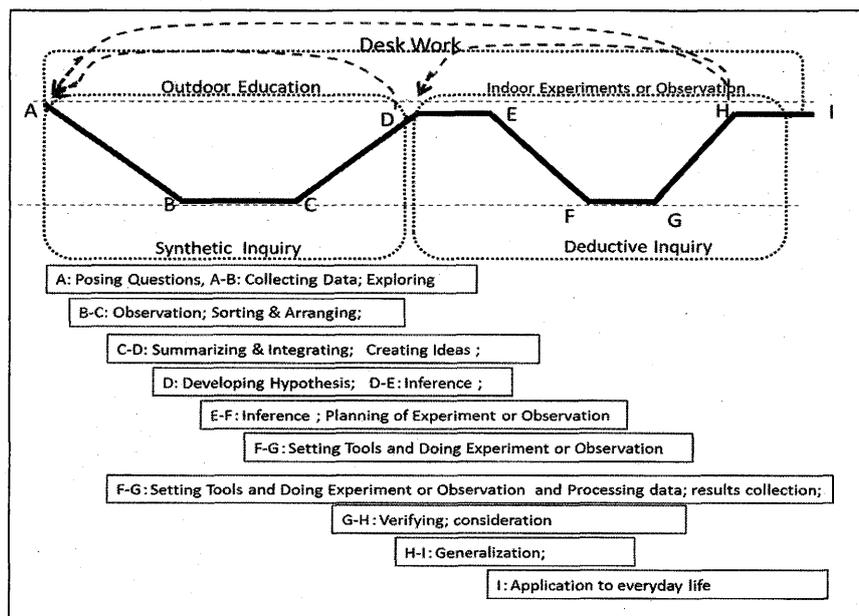


Figure 2. W-style Problem-Solving Model (Goto & Kobayashi, 2009)

These scientific processes hold that students can develop scientific hypotheses and other scientific skills that are just like the process of hypothesis-forming and other skills used by scientists. On the other hand, when students conduct scientific research with a scientist, the W-type problem-solving model becomes very important for conducting scientific inquiry over the long term.

### 3.2. Analysis of Questionnaire Results

In Table 1, A shows that about 70% of the students were able to determine that the hypotheses developed by the middle school students were different from those developed by scientists. Only 28.8% of students answered B that the hypotheses developed by middle school students were exactly the same as those developed by scientists. Finally, only one student explained that he/she could not decide whether students' hypotheses were same as scientists' hypotheses.

Also, the questionnaire asked the reasons why respondents took position A, B, or C.

Table 1. Student Results for Hypotheses (2013 and 2014)

	Students Number	Percentage
A	31+25(56)	70.0 %
B	7+16 (23)	28.8 %
C	1+0 (1)	1.3 %
Total	80	100

Table 2. Students' Reasons for Choosing A, B, or C

Types of Reasons	Samples of Reasons
A-1	Hypotheses of scientist always concern ideas that have not been developed by the scientific community, whereas the hypotheses of students always concern ideas already investigated by scientists, and for which all science teachers know the correct answers.
A-2	This time middle school students are asked to develop a hypothesis about three variables that affect cloud formation. They are asked to develop a hypothesis for which the results of the following experiments are already known by teachers, but not by students. However, hypotheses developed by scientists are those for which the scientific community has no real results.
B-1	Students' hypotheses are exactly the same as scientists' hypothesis. This is because both of them generate hypotheses based on their curiosity about natural phenomena as a result of their experience or knowledge.
B2	Scientists can generate hypotheses for their scientific questions using scientific knowledge and facts that they already have. These hypotheses generated by the students regarding cloud formation are also quite similar to those generated by scientists. Therefore, we can say that they are the same.
C1	Only one student could not decide whether students' hypotheses were same as scientists' hypotheses.

These results show that most of the students, who were in the second year of an undergraduate major in science education were able to identify the differences in the hypotheses between scientists and middle school students. In the Japanese context, this does not reflect the average understanding of science teachers in elementary and junior high schools. This is because most of the methods courses in science education do not cover the nature of science in detail. Also, there are many science teachers who do not write real scientific papers. Thus, it can be suggested that there are a lot of science teachers in Japan who would respond in ways similar to Type B or Type C.

### 3.3. The US Context

On the other hand, a review of the development of scientific processes in the United States, for example "Origins of Contemporary Instructional Models," shows that the 5E Model was developed as an initial BSCS process in scientific learning. The theoretical background of 5E was originally based on Dewey's Science in General Education (1938), the four models of Herbert (1901), as well as Dewey's How We Think (1910) and Democracy and Education (1916). Heiss, Obourn, and Hoffman (1950) was the first study cycle (learning cycle) that began using the term. The contents were subsequently refined, and this led to the teaching models of Myron Atkin (1961) and Robert Karplus (1967). The SCIS (Science Curriculum Instruction Study) then appeared, and continued to be studied by many educational psychologists and science education scholars. The BSCS 5E model appeared in the 1980s as a culmination of these studies (Figure 3).

In 1996, Lochhead and Yager described specific activities useful for constructivist learning, as follows:

1. Encouraging and accepting student autonomy, initiation, and leadership.
2. Allowing student thinking to drive lessons. Shifting to content and instructional strategies that are based on student responses.
3. Asking students to elaborate on their responses.

4. Allowing wait time after asking questions.
5. Encouraging students to interact with each other and with you.
6. Asking thoughtful, open-ended questions.
7. Asking students to articulate their theories about concepts before accepting teacher (or textbook) explanations of the concepts.
8. Looking for alternative concepts of students, and designing lessons to address any misconceptions, (Lochhead & Yager, 1996, p. 31)

Then they developed the four steps of the constructivist strategy, namely, invitation, exploration, proposing explanations and solutions, and taking action. On 2000, the NSTA (National Science Teachers Association) developed a position statement on scientific inquiry that was influenced by the National Science Education Standards developed in December 1995.

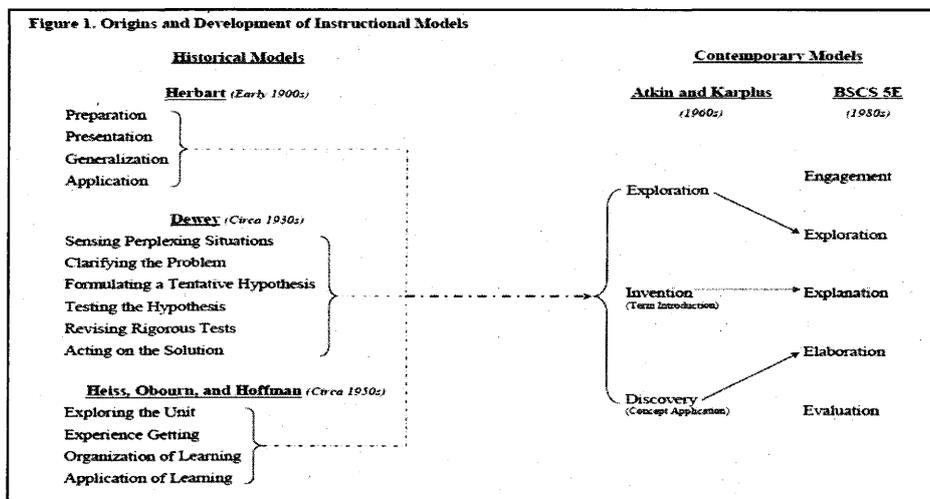


Figure 3. The 5E Teaching Model of BSCS and its Historical Relation to Other Models (Bybee, R.W, et al: p. 13, 2006)

This position statement states that the BSCS 5E learning cycle is one approach to the learning of scientific inquiry. At the same time, the statement acknowledges that there is not only one stable model of scientific inquiry because scientific processes are mostly different depending on the area of science. According to the statement:

*“There is no fixed sequence of steps that all scientific investigations follow. Different kinds of questions suggest different kinds of scientific investigations.” (NSTA, “Scientific Inquiry”)*

In 2003, the Coupled Inquiry Cycle was introduced as an interesting model (Figure 4, John A. Dunkhase, 2003).

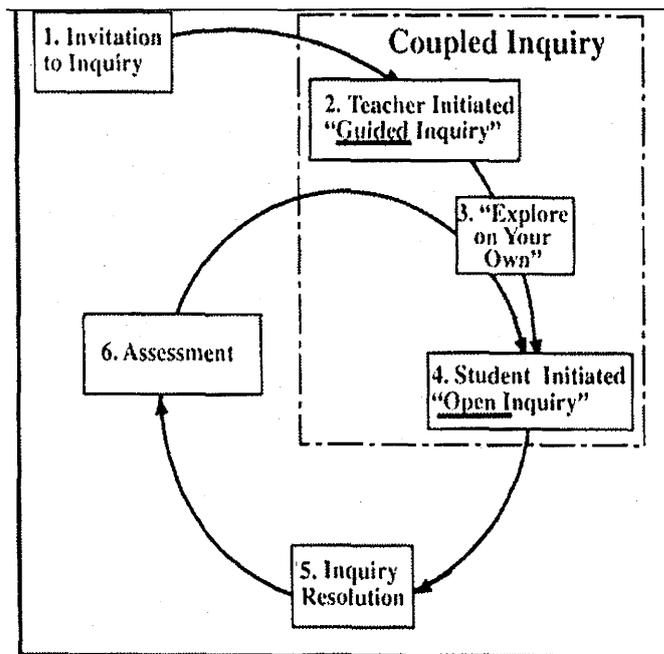


Figure 4. Coupled Inquiry Cycle (Dunkhase, p12, 2003)

In coupled inquiry, there are two parts to inquiry. One is teacher-initiated guided inquiry, and the other is student-initiated open inquiry. Also, coupled inquiry includes five steps, namely, questioning, investigation, evidence, explanation, and presentation. This model is a much more practical model for most science teachers. Here, it is clear that most of the models do not use hypotheses. Instead, hypotheses might be included in questioning or investigation.

Furthermore, regarding the nature of science in the NGSS (Next Generation Science Standards), published in April 2013, the chapter titled “Science Models, Laws, Mechanisms and Theories Explain Natural Phenomena” described the middle school stage as follows:

- *Theories are explanations for observable phenomena.*
- *Scientific theories are based on a body of evidence developed over time.*
- *Laws are regularities or mathematical descriptions of natural phenomena.*
- *A hypothesis is used by scientists as an idea that may contribute important new knowledge for the evaluation of a scientific theory.*
- *The term “theory” as used in science is very different from its common use outside of science.*

This description suggests the necessity of understanding certain theories, laws, and hypotheses for scientific research among scientists but not for every school science lesson. The NGSS officially declares that design, as the most important feature of engineering, should be taught as a part of the school science curriculum (Figure 5).

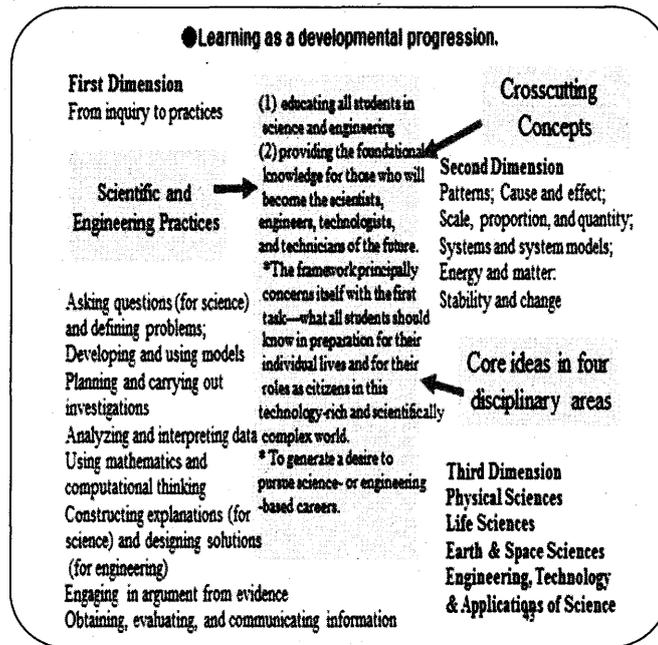


Figure 5. The New Framework of American Science Education

In this context, whether we should introduce features of engineering in science lessons or not will become an important issue in many discussions related to changes in the content of the National Curriculum Standards of Japan.

#### 4. Discussion

So far, we have roughly summarized the recent development of scientific inquiry in science education in Japan and the United States. In this section, we would like to compare the teaching of scientific inquiry in the US to the W-style problem-solving model developed by Goto and Kobayashi (2009).

The W-style problem-solving model is quite unique in that it includes the scientific processes of fieldwork and laboratory activities. However, these processes are so complicated that teacher training is very much needed. On the other hand, it can be said that most US models are much simpler and practically adaptable.

In the Japanese context, there are many sentences using “hypothesis or prediction” in the teacher’s guidebook for the Course of Study especially in the elementary schools. Many teachers use these terms, but in most cases, they do not have exactly the same meaning as a scientific hypothesis. In the middle school guidebook, there are fewer uses of the term “hypothesis.” There are some arguments that this term should only be used by real scientists or by students engaged in scientific investigation with real scientists.

#### 5. Conclusion

This study has examined the scientific processes in the science portion of the Course of

Study of Japan. Also, a comparative study of scientific processes in the US was conducted of Japanese models, the BSCS model, Yager's model, NGSS, and other models. In particular, the W-type problem-solving model developed in 2009 was focused on in comparison with other models. The results suggest that as science lessons approximate the activities of scientists, the W-type problem-solving model is the appropriate model. Long-term scientific inquiry by students can also be conducted using the W-type problem-solving model. However, the terms "problem-solving" and "hypothesis" are not synonymous in Japan and the US. However, the W-type problem-solving model can inform important discussions regarding the revision of the Course of Study of Japan in the next framework.

In the Japanese context, more and more emphasis is being placed on conducting real scientific inquiry as part of science education both in and outside of school. Now is the time to develop a better system in which everybody enjoys doing science in their everyday life in Japan.

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(和文要旨)

### 野外及び室内での理科授業における科学の方法に関する課題：日本の理科授業における科学の方法と NGSS までのアメリカの科学の方法に関する変遷の比較研究

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日本の現行の学習指導要領では、科学の方法領域において、小学校では学年ごとに重点化される内容が示され、その一方、中学校においては、科学の方法を学年ごとに分解することはなく、「結果を分析し解釈する」という文言で示されている。基本的には中学の理科の学習はより、自然科学者の科学研究に近づくことから、実験や観察に存在する科学的見方や考え方を分解して指導することに無理があるとの解釈による。

一方、アメリカでの流れを確認すると、例えば、BSCSでは、「今日的教授モデルの起源」と題して、科学的な見方や考え方に關して、アメリカの歴史の変遷を示しながら、BSCS独自の5Eモデルを作り上げた。このほかにも、Yager氏のモデルやDunkhase氏のモデルなどがある。NSTAとして、科学の方法や科学の本質における声明文の中で、科学の方法は研究分野によりさまざまに固定した科学の方法はないことを明言し、また、2013年の4月にできたNGSS（次世代科学スタンダード）の科学の本質においても、科学者の探究モデルを日々の科学実験・観察と対応させてはいない。さらに、NGSSでは科学の方法のみならず工学の本質であるデザインすることを科学の授業の中に正式に位置づけた。本論文では、アメリカにおける科学の方法、科学的探究学習の昨今の流れをまとめ、五島・小林（2009）の「W型問題解決モデル」との比較が行われた。さらに、2013年度と2014年度の理科教育の学部2年の学生の科学の方法に関する考え方を分析した。日本においては、科学者が寄り添って、児童生徒が科学研究を進める場合、W型問題解決モデルは大変重要であり、長い時間をかけて展開が可能である。結論として、理科における「問題解決モデル」の文言と海外の科学教育学における「問題解決モデル」とは同義とはいえない。しかし、次期学習指導要領の改訂に向けて、科学の方法に関する有用な論を展開しており、議論の対象にすべきモデルである。