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TEACHING OF CRITICAL THINKING SKILLS BY SCIENCE TEACHERS IN JAPANESE PRIMARY SCHOOLS

Hiroyoshi Kinoshita

Abstract. *The importance of critical thinking in science education is widely recognized. However, little research has been conducted on the teaching of critical thinking by teachers. If actual teaching conditions of teachers in the classroom are clarified, effective teaching methods for developing critical thinking in students could be developed. This study administered a questionnaire survey to ascertain how science teachers teach critical thinking in Japanese primary schools. The study population consisted of 291 Japanese primary school teachers with teaching careers spanning 1–38 years. The survey revealed the following. (1) Teachers taught students the importance of conducting experiments by themselves to obtain results. However, teachers did not sufficiently teach students the need to conduct multiple experiments before reaching a conclusion, improve data reliability before making decisions, or examine their conclusions carefully given incomplete data. (2) Compared to teachers with shorter teaching careers, teachers with longer careers taught critical thinking more effectively, particularly in terms of emphasizing positivity and maintaining a healthy skepticism. (3) Teachers who taught emphasized positivity and encouraged multifaceted thinking were more likely to teach about emphasized evidence. The corresponding causal relationship analysis suggests that teaching that emphasizes positivity and encourages multifaceted thinking is key to promoting evidence-oriented instruction.*

Keywords: *science learning, critical thinking skills, in-service teachers, teaching skills, teachers' training*

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Introduction

These days, people are surrounded by an overflow of information, making it easy for them to access countless types of information in vast quantities. Although some information may be unsubstantiated, false, or represent pseudoscience, people tend to believe the information they encounter without question. To rise above this tendency, people need to develop critical thinking skills. Paul and Elder (2001) identified two types of critical thinking, one in which others' opinions and ideas are the object of critical thinking and the other in which one's own opinions and ideas are the object. The latter is more progressive because it is not easy to think critically about one's own ideas when one has received or relies on unsubstantiated or incorrect information. The same is true in education: It is not easy for students to verify the authenticity of the information they receive and examine their decisions to ensure that they are not making assumptions or overlooking something. Thus, it is important for students to develop critical thinking skills for more effective learning.

This idea has now become a global trend in education, with critical thinking and other skills and competencies receiving substantial attention (Sutiani et al., 2021). One representative example is the "21st Century Skills" proposed in the Assessment and Teaching of 21st Century Skills Project: ATC21S (Griffin et al., 2012). These skills are grouped into four categories—"ways of thinking," "ways of working," "tools for working," and "living in the world"—and include critical thinking. The Organization for Economic Co-operation and Development Future of Education and Skills 2030 Project has also identified three categories of skills as learning competences for achieving wellbeing in 2030—"cognitive & meta-cognitive," "social & emotional," and "physical & practical"—and also includes critical thinking. Based on these international trends, the National Institute for Educational Policy Research (NIER, 2013) has proposed "21st century competencies" that are skills necessary for students to survive in the 21st century. These fall into the three categories of "basic skills," "thinking skills," and "practical skills," and then again, include critical thinking. Despite the increasing awareness of the importance of critical thinking, research on students' critical thinking is still in its infancy, although several related studies have been conducted (Pasquinelli et al., 2021). Specifically,

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few research reports regarding teachers' teaching skills on critical thinking have been published. Toward filling this gap, this study examined teachers' teaching skills on critical thinking, particularly the case of science teachers in Japanese primary schools.

Theoretical Background

Critical thinking has been extensively studied in the West since the 1930s. The background was the wartime propaganda movement, during which people had to develop critical thinking in order to resist declarations, doctrines, and so on. In the United States, "The Eight-Year Study (1933–1941)" was spearheaded by The Progressive Education Association, which actively conducted research on critical thinking. Since then, many researchers have defined critical thinking from their own perspectives, and controversy has ensued.

For example, according to Ennis (1962), a famous critical thinking researcher, critical thinking is defined as the ability to correctly assess statements, which is independent of the subject matter and context and can be generalized. By contrast, McPeck (1981) argued that critical thinking is not generalizable because it depends on the subject matter and context. Later, Ennis (1987) revised his own definition, stating that critical thinking is reasonable, reflective thinking that is focused on deciding what to believe or do. Thus, the concept has been modified or expanded in discussions among researchers. Despite the lack of consensus, these definitions have some commonalities, such as reflective, rational, and skeptical perspectives.

Critical thinking has also received attention in science education, where researchers and practitioners consider it necessary for students to acquire not only science knowledge and skills but also critical thinking (Byrne & Johnstone, 1987). A review of the literature on critical thinking in science education reveals several important studies. Relevant published studies can generally be classified into four categories. The first category comprises studies on the development of critical thinking measures, such as the work of Mapeala and Siew (2015), who presented science content to primary school students and created questions that were answerable on a four-point scale. When answering the questions, students were instructed to select the relevant items from the following categories to demonstrate critical thinking: comparing objects; ordering; and identifying cause and effect. However, this measurement method does not easily capture the details of thinking methods and situations. Meanwhile, Forawi (2016) developed the Critical Thinking Attribute Survey (CTAS) instrument to measure university students' critical thinking. The CTAS is designed to measure conclusions; it can measure the accuracy of statements, the soundness of reasoning, and the interpretation of claims and results used to draw conclusions.

The second category concerns the assessment of critical thinking, which includes the work of Dowd et al. (2018), who used the Biology Thesis Assessment Protocol to assess scientific reasoning in university students and the California Critical Thinking Skills Test to measure critical thinking, and then analyzed the relationship between the two. Gómez and Suárez (2020) analyzed the relationship between inquiry-based teaching (IBT) and critical thinking using the results of the 2015 PISA test. The results revealed a positive association between IBT and students' self-reported critical thinking.

The third category concerns the development of critical thinking. For example, Hussein et al. (2019) focused on the inquiry, communication, mystery, decision-making, challenge, and reward perspectives and designed an educational computer game. After testing the game's effectiveness in primary science units on "biological food relations," "plant life processes," and "energy," the authors reported significant improvements in students' critical thinking. Meanwhile, Rowe et al. (2015) developed a teaching method that includes three elements: incorporating case studies, such as the vaccine vs. autism debate; teaching the basics of argumentation and logical fallacies; and contrasting science and pseudoscience. The effectiveness of the teaching method was tested in a university "Foundations of Science" course, which revealed significant improvements in students' critical thinking.

The fourth category concerns teacher education (pre-service and in-service). Arsal (2017) investigated the impact of inquiry-based learning on the critical thinking of pre-service teachers. The results revealed no significant difference in the pre-service teachers' critical thinking in the experimental and control groups. In addition, the study suggested that microteaching is effective in developing pre-service teachers' critical thinking. Ariza et al. (2021) noted that in-service teachers tended to replicate the teaching models they experienced as students and designed several training activities for pre-service teachers. The results of the activities revealed that pre-service teachers recognized encouraging students to think critically as an important part of the teacher's role. While many studies discussed above have investigated the assessment and development of critical thinking, few have focused on teacher education in this context. Ma et al. (2021) noted that although the importance of critical thinking in

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science education has been widely recognized worldwide, scant research on the subject has been conducted.

Aims and Research Questions

Although the importance of critical thinking in science education is widely recognized, it has been assumed that in-service teachers in some countries, including Japan, do not know how to teach critical thinking skills and instead focus on teaching knowledge (Ariza et al., 2021; Forawi, 2016; Kinoshita, 2013). Research is needed in this area given the insufficiency of prior studies on science teacher education. Specifically, a survey into the reality of science education, which has yet to be clarified, is urgently needed. If the details of science teachers' actual teaching conditions can be clarified, effective teaching methods may be developed to help students cultivate critical thinking.

To those ends, this study clarifies the details of the conditions of science teachers' teaching of critical thinking in Japanese primary schools by surveying science teachers through a questionnaire. In this study, Ennis's (1987) definition of critical thinking, "reasonable, reflective thinking that is focused on deciding what to believe or do," which is frequently cited in previous research, was used. For this purpose, three research questions were set:

(1) Do primary school science teachers in Japan provide instruction that acquires critical thinking in their students? If so, what kind of instruction do they provide?
(2) Do the teaching skills of science teachers differ according to the length of a teaching career? If so, what differences in teaching contents exist between teachers with long versus short teaching careers?
(3) Focusing on the science teachers' teaching skills factors, what is the structure of these factors? With reference to the factor structure, what can be done to improve teachers' teaching skills?

Research Methodology

Research Design

First, a questionnaire was developed to measure how primary science teachers teach critical thinking to their students. Second, a survey of primary science teachers was conducted using the questionnaire, and factor analysis and analysis of variance (ANOVA) were performed on the responses obtained to determine the teachers' teaching conditions. Finally, a causal model was created using structural equation modeling (SEM) to identify the factor relationships that influence science teachers' teaching contents.

Research Sample

The survey was conducted between June 2021 and February 2022 using a questionnaire. The study population consisted of 291 (136 male and 155 female) primary school teachers in the Hokkaido, Tokyo, Toyama, Okayama, and Hiroshima prefectures in Japan. Primary schools in Japan are a compulsory six-year course, from grades 1 to 6. Generally, the primary school teachers teach all curricular subjects, although some teachers do not teach science. This survey's teachers' teaching careers ranged from 1 to 38 years, and all taught science classes. For this reason, this study describes primary school teachers as science teachers. To eliminate as much bias as possible related to the study area, the survey was conducted in five different urban areas. Written consent was first obtained from the school principals and then the participating teachers. The gender and career-length proportions of the science teachers surveyed were dominated by female teachers, many of whom had long careers. This is generally representative of the primary school teachers' population in the country. The questionnaires were distributed to participants in person by the researcher, and the collection rate was 100%. The survey was subjected to a research ethics review by Hiroshima University, and approval was obtained (approval number: 2021051).

Questionnaire Development

This study examined prior research for a scale to measure in-service teachers' critical thinking teaching skills with students in science classes but was unable to locate any such scale. Accordingly, the author then referred to measures of students' critical thinking. The Watson and Glaser Critical Thinking Appraisal (Watson et al., 2002) and California Critical Thinking Disposition (Banning, 2006) questionnaires are often used to measure inference, recognition of assumptions, inquisitiveness, and other general aspects of critical thinking (Forawi, 2016). However,

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as subject matter and context are important in critical thinking, questions that correspond to the reality of science classes must be prepared. From this standpoint, Kinoshita et al. (2013), Kinoshita and Yamanaka (2014), and Kinoshita (2015) focused on science classes from primary to high school and developed questionnaire items that capture students' critical thinking level. These questionnaire items were confirmed for validity and reliability through statistical methods. The items for primary school students consisted of four factors: "reflective thinking," "inquisitive and rational thinking," "emphasis on evidence," and "healthy skepticism" (20 items). Items for secondary school students consisted of four factors: "exploratory and rational thinking," "multifaceted thinking," "reflective thinking," and "healthy skepticism" (23 items). The items for high school students consisted of five factors: "emphasis on data collection and interpretation," "emphasis on demonstrability and reproducibility," "inquisitive thinking," "healthy skepticism," and "emphasis on objectivity" (20 items).

The questionnaire items for teachers were developed based on the above-mentioned questionnaire items for students. In other words, the content of the questionnaire items was converted from the perspective of those who receive science lessons to those who teach them. Three teachers teaching primary school teacher training at a university and two teachers at a university-affiliated primary school examined the content and wording of the questionnaire items and prepared 40 items. To achieve an authentic measurement, the subjects were not informed at the time of the survey that it was a survey on the teaching of critical thinking. The survey was designed to clarify teachers' actual teaching practices in science classes. The participants were instructed to "Please answer the questionnaire as you think it should be answered." Under the instruction that "We will not identify or evaluate individuals," the subjects were asked to answer the questionnaire using a five-point Likert scale: (1) not applicable, (2) not very applicable, (3) neither applicable nor not applicable, (4) somewhat applicable, and (5) applicable. The numbers of the responses were used as scores as they were. However, scores were reversed for Q2, Q5, Q9, Q11, Q14, Q15, Q19, Q35, Q37, and Q38, as can be seen in Table 1. In addition, a column for an open-ended question was provided so that respondents could state what they paid special attention to when teaching science in the classroom (Table 1). The following attributes were also reported: gender, number of years of teaching career, whether they had received training in science, and whether they were uncomfortable with science instruction.

Table 1
Questionnaire Items

Q1	When students disagree with each other, you instruct them to reflect on their ideas once.
Q2^R	When students disagree with each other, you instruct them to decide by majority vote.
Q3	You instruct students not to believe an opinion just because many people agree with it.
Q4	You instruct students to consider multiple causes for a single outcome.
Q5^R	You instruct students to ignore data that cannot be explained.
Q6	You instruct students to repeat the experiment multiple times.
Q7	You instruct students to think about whether there are other ways to do the experiment before they do it.
Q8	You instruct students to focus on the experimental data they have obtained and to make decisions.
Q9^R	You do not require students to experiment when they already know the scientific law or principle.
Q10	You instruct students to give reasons for their opinions.
Q11^R	You do not require students to repeat the same experiment after they have obtained the expected experimental results.
Q12	You instruct students to check if there are any conditions they have overlooked before drawing their conclusions.
Q13	You instruct students to collect as much experimental data as possible.
Q14^R	You do not require students to experiment subsequently in a different manner when they have obtained the expected experimental results.
Q15^R	You do not require students to experiment when the results are obvious without the need to experiment.
Q16	You instruct students not to trust the results of a single experiment.
Q17	You instruct students not to draw conclusions when they do not have all the experimental data.

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Q18	You instruct students to conduct the experiment even though they can predict the outcome of the experiment.
Q19 R	You instruct students to use the information they find on the Internet if they do not get the expected experimental results.
Q20	You instruct students to make decisions based on evidence.
Q21	You instruct students to conduct the experiment even though they already know the scientific law or principle.
Q22	You instruct students to check the experimental data for errors.
Q23	You instruct students to check for errors in experimental procedures when they are unable to collect experimental data successfully.
Q24	You instruct students not to trust a statement just because it is from a textbook.
Q25	You instruct students not to trust the information they find on the Internet just because they have looked it up.
Q26	You instruct students to try new things.
Q27	You instruct students to think about any oddities in the experimental results when they are obtained.
Q28	You instruct students to keep the conclusions to what is derived from the experimental data.
Q29	You instruct students to be objective and to interpret the experimental data.
Q30	You instruct students to focus on both sides of what the experiment revealed and what was not revealed.
Q31	You instruct students not to ignore experimental data just because it is inconvenient.
Q32	You instruct students to think things through until they are satisfied with themselves.
Q33	You instruct students to try different methods when one method does not solve the problem.
Q34	You instruct students to look for better ideas even when they come up with good ones.
Q35 R	You instruct students to use the data presented in the textbook when they have not successfully collected experimental data.
Q36	You instruct students to check for errors in the way the experiment was conducted.
Q37 R	You instruct students to use the results presented in the textbook when they do not obtain the expected experimental results.
Q38 R	You do not require students to perform an experiment if the experiment is a simple one.
Q39	When a student's experiment does not go well, you instruct students to think about what went wrong.
Q40	You instruct students not to make assumptions about the results of the second experiment based solely on the results of the first experiment.
When you are teaching a science class, what is your particular focus during the class?	

Note: R means reverse.

Validity and Reliability Analysis

To examine the validity of the created questionnaire items, factor analysis (principal factor method and promax rotation) was conducted. Items with loadings of .35 or higher were designated as items within the factor structure. The factor analysis was repeated except for items that did not meet this criterion, and five factors were extracted (Table 2). Factor 1 was labeled "multifaceted thinking" because it consisted of items such as "Before conducting an experiment, have students think about whether there are other experimental methods" and "Before drawing a conclusion, have students check if there are any conditions they have overlooked." Factor 2 was labeled "emphasis on demonstrability" because it consisted of items such as "Have students conduct experiments even if they know the scientific rules involved" and "Have students conduct experiments even if they can predict the results of the experiments." Factor 3 was labeled "emphasis on evidence" because it consisted of items such as "Have students not draw conclusions when the necessary experimental data are not available," and "Have students not believe opinions just because many people agree with them." Factor 4 was labeled "healthy skepticism" because it consisted of items such as "When experimental data were not obtained successfully, have them use data presented in textbooks (R)" and "When the expected experimental results were not obtained, have them use information from the Internet (R)." Factor 5 was labeled "emphasis on objectivity" because it consisted of items such as "Have the participants interpret

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the experimental data with an objective attitude" and "Have the participants make judgments with emphasis on the experimental data obtained."

The reliability coefficients (Cronbach's α) for each factor were then calculated to examine the questionnaire items' reliability. The results showed that .531 ≤ α ≤ .810, thus confirming the internal consistency of each factor.

Based on the above, the researcher concluded that the created questionnaire items were valid and reliable in capturing the reality of teachers' critical thinking in science classes. SPSS Ver. 28 was used for the analysis.

Table 2
Factor Analysis

	F1	F2	F3	F4	F5
Q11 R	.714	.155	.246	.079	.008
Q14 R	.659	.206	.133	.024	.112
Q7	.568	.062	.238	.027	.084
Q33	.567	.073	.092	.020	.034
Q12	.548	.091	.271	.079	.072
Q30	.547	.221	.081	.004	.250
Q34	.514	.034	.126	.044	.062
Q6	.397	.011	.059	.085	.239
Q21	.097	.718	.201	.069	.059
Q18	.220	.664	.194	.040	.119
Q9 R	.094	.640	.117	.015	.023
Q38 R	.122	.591	.044	.064	.064
Q15 R	.194	.575	.099	.140	.027
Q40	.014	.021	.679	.054	.016
Q39	.035	.095	.605	.036	.051
Q17	.001	.039	.491	.135	.042
Q4	.316	.032	.412	.035	.144
Q3	.147	.230	.392	.091	.135
Q37 R	.030	.041	.108	.950	.080
Q35 R	.014	.013	.059	.821	.004
Q19 R	.040	.133	.025	.382	.110
Q28	.008	.039	.148	.058	.563
Q29	.193	.010	.127	.019	.527
Q8	.041	.128	.044	.103	.472
F1	-	.213	.450	.320	.304
F2		-	.344	.104	.191
F3			-	.097	.471
F4				-	.117
F5					-

Note: R means reverse.

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Research Results

Comparison of Factor Scores

It can be inferred that the teaching of critical thinking is not uniform and that some matters are carefully taught while others are poorly taught. Therefore, based on the responses obtained, this study analyzed the reality of how primary science teachers teach their students to develop critical thinking. First, for each of the five factors obtained, the mean of the scores of the items comprising the factor was calculated, and this was used as the subscale score (Table 3). Next, a one-way analysis of variance was conducted to determine whether significant differences existed among the scores of the five factors (Table 4). The results showed a significant main effect on the mean of the scores for each factor (F (1, 290) = 23,354.897, $p < .01$). Therefore, multiple comparisons were performed using Bonferroni's method to determine which scores had significant differences between them (Table 5). The results showed significant differences among all scores. The highest score was for "emphasis on empirical evidence," with a value greater than 4.00, while the lowest score was for "emphasis on evidence," with a value of less than 3.00.

Table 3
Means and Standard Deviations for Each Factor

Factor	*M*	*SD*
Multifaceted thinking (F1)	3.41	0.65
Emphasis on demonstrability (F2)	4.32	0.58
Emphasis on evidence (F3)	2.81	0.83
Healthy skepticism (F4)	3.97	0.54
Emphasis on objectivity (F5)	3.70	0.59

Note: N = 291.

Table 4
One-Way Analysis of Variance Between the Five Factors Scores

	SS	*df*	*MS*	*F*
Factor	19278.359	1	19278.359	23354.897**
Residuals	239.381	290	.825	

Note: ** means $p < .01$.

Table 5
Multiple Comparisons of Factors

	MD				
	Multifaceted thinking	Emphasis on demonstrability	Emphasis on evidence	Healthy skepticism	Emphasis on objectivity
Multifaceted thinking	–	.910**	.587**	.564**	.290**
Emphasis on demonstrability		–	1.497**	.346**	.620**
Emphasis on evidence			–	1.150**	.877**
Healthy skepticism				–	.274**
Emphasis on objectivity					–

Note: ** means $p < .01$.

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Comparison by Teaching Career

It is inferred that differences exist in the teaching of critical thinking between teachers with long and short teaching careers. As such, this study divided teachers into five groups according to the number of years of teaching experience and analyzed whether differences in instruction existed. First, teachers who did not describe their teaching career years in the attribute items of the questionnaire were excluded from the analysis, and the remaining 288 teachers were categorized into Career 1 (5 or less years of teaching), Career 2 (6–10 years of teaching), Career 3 (11–20 years of teaching), Career 4 (21–30 years of teaching), and Career 5 (31 or more years of teaching; Table 6). The Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the Board of Education consider life stage categories of 1, 5, 10, and 20 years of teaching and provide legal training accordingly. The groups were thus classified based on this idea.

Next, an ANOVA was conducted with the factor as the dependent variable and teaching career as the independent variable (Table 7). The results showed significant main effects on the mean of the scores for "emphasis on demonstrability" (F (4,283) = 2.874, $p < .05$), "healthy skepticism" (F (4,283) = 8.370, $p < .01$), and "emphasis on objectivity" (F (4,283) = 5.438, $p < .01$). Thus, multiple comparisons were conducted using Bonferroni's method to determine which scores had significant differences among them. The results showed that for "emphasis on demonstrability," the mean of the scores was significantly higher for Career 2 teachers than for Career 1 teachers (Table 8). For "healthy skepticism," the mean of the scores was significantly higher for Careers 4 and 5 teachers than for Career 1 teachers, and for Career 4 teachers than for Careers 2 and 3 teachers (Table 9). Furthermore, for "emphasis on objectivity," the mean of the scores was significantly higher for Careers 4 and 5 teachers than for Career 1 teachers, and for Careers 4 and 5 teachers than for Career 3 teachers (Table 10).

Table 6
Means and Standard Deviations for Career Groups in Each Factor

Factor	Career Group	*N*	*M*	*SD*
Multifaceted thinking (F1)	1	71	3.308	.622
	2	55	3.384	.688
	3	55	3.375	.584
	4	65	3.471	.639
	5	42	3.490	.771
Emphasis on demonstrability (F2)	1	71	4.119	.706
	2	55	4.458	.503
	3	55	4.386	.575
	4	65	4.314	.601
	5	42	4.332	.555
Emphasis on evidence (F3)	1	71	2.861	.744
	2	55	2.806	.816
	3	55	2.788	.837
	4	65	2.718	.880
	5	42	3.008	.915

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Factor	Career Group	*N*	*M*	*SD*
Healthy skepticism (F4)	1	71	3.716	.581
	2	55	3.931	.489
	3	55	3.935	.566
	4	65	4.215	.446
	5	42	4.084	.520
Emphasis on objectivity (F5)	1	71	3.521	.534
	2	55	3.733	.572
	3	55	3.521	.429
	4	65	3.862	.598
	5	42	3.881	.732

Table 7
ANOVA with Factor as Dependent Variable and Teaching Career as Independent Variable

	Source of variation	*SS*	*df*	*MS*	*F*
Multifaceted thinking	Between groups	1.320	4	.330	.768
	Within groups	121.616	283	.430	
	Total	122.936	287		
Emphasis on demonstra-bility	Between groups	4.151	4	1.038	2.874*
	Within groups	102.175	283	.361	
	Total	106.326	287		
Emphasis on evidence	Between groups	2.340	4	.585	.843
	Within groups	196.504	283	.694	
	Total	198.845	287		
Healthy skepticism	Between groups	9.181	4	2.295	8.370**
	Within groups	77.605	283	.274	
	Total	86.786	287		
Emphasis on objectivity	Between groups	7.103	4	1.776	5.438**
	Within groups	92.079	283	.327	
	Total	99.182	287		

Note: * and ** mean $p < .05$ and $p < .01$, respectively.

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Table 8
Multiple Comparisons of Factors (Emphasis on Demonstrability)

	MD				
	Career 1	Career 2	Career 3	Career 4	Career 5
Career 1	–	.339*	.267	.195	.213
Career 2		–	.072	.144	.126
Career 3			–	.072	.054
Career 4				–	.018
Career 5					–

Note: * means $p < .05$.

Table 9
Multiple Comparisons of Factors (Healthy Skepticism)

	MD				
	Career 1	Career 2	Career 3	Career 4	Career 5
Career 1	–	.215	.219	.499**	.368**
Career 2		–	.004	.284*	.153
Career 3			–	.280*	.149
Career 4				–	.131
Career 5					–

Note: * and ** mean $p < .05$ and $p < .01$, respectively.

Table 10
Multiple Comparisons of Factors (Emphasis on Objectivity)

	MD				
	Career 1	Career 2	Career 3	Career 4	Career 5
Career 1	–	.212	.000	.341**	.360*
Career 2		–	.212	.129	.148
Career 3			–	.341*	.360*
Career 4				–	.019
Career 5					–

Note: * and ** mean $p < .05$ and $p < .01$, respectively.

Structural Analysis of Factors

Five factors related to the teaching of critical thinking were extracted, and a detailed analysis of these factors revealed that "emphasis on demonstrability" scored high, indicating that teachers provided careful instruction. Meanwhile, scores for "emphasis on evidence" were low, indicating issues in teaching. Regarding teaching careers, "emphasis on demonstrability" scores were generally high for all experience levels, but Career 2 teachers taught more effectively than Career 1 teachers. There was no difference in teaching "emphasis on evidence" by career length, and scores were

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generally low for all experience levels, indicating issues in teaching. In addition, teachers with longer careers tended to score higher in "healthy skepticism" and "emphasis on objectivity," indicating that they provide detailed guidance.

Based on the above, this study determined that of the five factors, "emphasis on evidence" is the most problematic and needs to be improved. As such, the author conducted a structural analysis of the causal relationship among the five factors and explored the possibility of improving "emphasis on evidence." In doing so, the factor structure was examined using "emphasis on demonstrability"—which scored high—as the key clue. As a specific procedure, a causal model was created via SEM, targeting "emphasis on evidence" and explaining it with four factors: "emphasis on demonstrability," "healthy skepticism," "multifaceted thinking," and "emphasis on objectivity" (Figure 1). In this study, the goodness of fit index (GFI), comparative fit index (CFI), and root mean square error of approximation (RMSEA) were used as goodness of fit indices for the causal model. Based on these goodness-of-fit indices, the goodness of fit between the created causal model and the sample data was examined, and it was determined that the created causal model and the sample data fit well enough considering GFI = .906, CFI = .937, and RMSEA = .043.

The direct, indirect, and total effects of factors influencing "emphasis on evidence" were then calculated (Table 11). The direct effect of "emphasis on demonstrability" on "emphasis on evidence" was .292, a significant path, although not relatively large. The overall effect was .490, a relatively large value. This indicates that teachers who emphasize empiricism in their science lessons are more likely to teach with a greater emphasis on evidence. Similarly, the direct effect of "emphasis on objectivity" on "emphasis on evidence" was .237, a significant path, although not relatively large. The overall effect was .491, a relatively large value. This indicates that teachers who teach with an emphasis on objectivity are more likely to teach with an emphasis on evidence. The direct and total effects of "multifaceted thinking" on "emphasis on evidence" were .438, which was relatively large, revealing that the more teachers teach multifaceted thinking, the more they emphasize the importance of evidence. Meanwhile, the indirect and total effects of "healthy skepticism" on "emphasis on evidence" amounted to .096, a relatively small value. This indicates that no causal relationship exists between "emphasis on evidence" and "healthy skepticism." Although not a direct effect of "emphasis on evidence," but the direct effect of "emphasis on objectivity" on "multifaceted thinking" was .580, a relatively large value. Amos Ver. 28 was used in the analysis.

Figure 1
Causal Model for "Emphasis on Evidence"

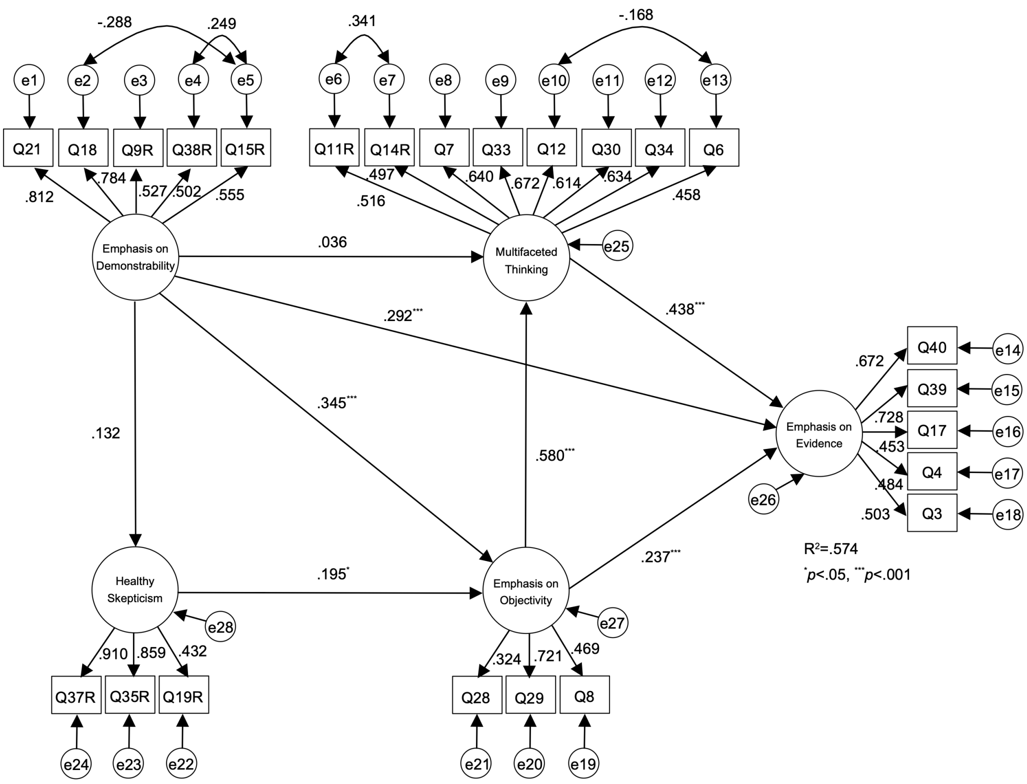

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Table 11
Effects of Factors Influencing "Emphasis on Evidence"

Factor	Direct Effect	Indirect Effect	Total Effect
Emphasis on demonstrability (F2)	.292	.198	.490
Healthy skepticism (F4)	.000	.096	.096
Multifaceted thinking (F1)	.438	.000	.438
Emphasis on objectivity (F5)	.237	.254	.491

Discussion

Based on the results obtained from the analysis of the survey responses, this study examined how Japanese science teachers teach critical thinking to their students, whether science teachers' teaching skills differ by length of a teaching career, and what causal relationships exist among factors related to instruction. First, regarding how teachers teach, the results presented in Tables 3, 4, and 5 show significant differences among all factors. Extracting the characteristics of these results, the highest scores were obtained for "emphasis on demonstrability," followed by "healthy skepticism."

Meanwhile, scores for "emphasis on evidence" were the lowest. Teachers instructed students to conduct experiments and check the results, even though the results were predictable, or the experiments were simple. In the open-ended section of the questionnaire (What do you particularly emphasize in the classroom when teaching science?), 70 of the 125 teachers who filled out the questionnaire indicated that in their teaching they emphasized having each student perform the experiment individually and letting them think of their own experimental methods. This indicates that teachers teach students the importance of conducting experiments on their own to obtain results because even the experimental results in textbooks or information obtained from the Internet may not always be as described, depending on the experimental method, environment, and other factors. Lesson studies and microteaching are generally popular in Japanese primary schools; through them, teachers may learn the importance of letting each student experiment by themselves (Lewis, 1995). Arsal (2017) conducted a survey of Turkish pre-service teachers and found that experiencing microteaching was effective in improving critical thinking, which is consistent with the finding in this study. However, teachers may not be aware that they are teaching critical thinking and may be teaching it unintentionally.

Moreover, teachers did not do enough to teach students to conduct experiments multiple times before drawing conclusions, to increase the reliability of their data before making judgments, or to examine their conclusions carefully when they do not have all the necessary data. Regarding critical thinking during science classes, the Kinoshita (2013) survey of primary school students revealed that many students were drawing conclusions without sufficient evidence. This indicates that the reality of teachers' teaching and students' learning coincide. In the current survey, only two of the 125 teachers who filled out the free response section of the questionnaire stated that they emphasized having students experiment repeatedly. In addition, only five teachers stated that they carefully instruct students on the rationale for decision-making. It is easy to encourage students to question the new things they face, but it is difficult to motivate them to reexamine their previously held beliefs and hypotheses and notice contradictions and inconsistencies. Therefore, teachers should ask students to check for hidden assumptions and to examine whether they are making judgments based on impressions or intuition. Specifically, teachers should ask, "Is that true in all cases?" and "Are there any oversights that need to be considered before you make a decision?" to guide students to think from various perspectives without being limited by their own assumptions or biased views. However, this study speculates that teachers may not have provided sufficient guidance because they did not know how to teach critical thinking skills. Alternatively, teachers may

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not have had the time to allow students to experiment multiple times or collect more information. In this regard, Oliveras et al. (2013) noted that the teachers in their study were not trained in critical thinking and lacked the time and resources to incorporate critical thinking into their lessons. The authors also noted that teachers generally lack the time and resources to incorporate critical thinking into their teaching. Similarly, Forawi (2016) noted that teachers do not know how to teach critical thinking skills. Kinoshita (2013), in a survey of Japanese science teachers, also found that teachers have difficulty in providing sufficient experiment and note-taking instruction within the class period (45 minutes). These are consistent with the ideas discussed above.

Next, regarding whether teachers' teaching skills differ by teaching career length, the results (Tables 6 and 7) indicate significant differences in "emphasis on demonstrability," "healthy skepticism," and "emphasis on objectivity." A detailed analysis of the results for "emphasis on demonstrability" (Table 8) shows that the mean of the scores was significantly higher for teachers in Career 2 than for teachers in Career 1. All career length categories had a mean value of scores higher than 4.000, indicating that, overall, "emphasis on demonstrability" is executed well. However, teachers with shorter teaching careers may not have provided adequate instruction because they were less experienced with lesson study. For example, teachers may have only transferred knowledge and not asked questions that encouraged critical thinking by students (Soysal, 2021). Teacher training programs in Japan tend to focus on teaching subject-specific knowledge and lack experience in practical classroom teaching. Therefore, one aspect of this is that pre-service teachers are therefore gaining experience after becoming teachers and improving their teaching skills by conducting lesson studies. By contrast, teachers with some years of teaching may have mastered the teaching methods and provided detailed instruction. Furthermore, more experienced teachers may also have been influenced by their frequently attending training sessions organized by MEXT and the Board of Education. For example, teachers participating in training sessions learn about the latest theories and develop new teaching materials and test questions. In addition, several teachers form groups to reflect on and discuss their own teaching methods and consider ways to improve them.

The detailed analysis of "healthy skepticism" (Table 9) shows that the means of the scores were significantly higher for Career 4 and 5 teachers than for Career 1 teachers. The mean of the scores was also significantly higher for Career 4 teachers than for Career 2 teachers. Like the aforementioned "emphasis on demonstrability," the tendency for teachers with longer teaching careers to teaching more carefully than teachers with shorter teaching careers was confirmed. In particular, it is inferred that teachers with less than five years of teaching experience, that is, Career 1 teachers, do not have the advanced skills to instruct students on skepticism concerning the results of experiments, and they struggle just to get students to conduct experiments. In Kinoshita's (2013) study, it was found that teachers with short teaching careers experience difficulties in teaching when their students do not get the expected experimental results. Thus, it is inferred that when teachers do not get the expected results, they instruct their students to gather information from textbooks or the Internet and draw conclusions on that basis. In the present study, the author conjectures that by contrast, teachers with more than 21 years of teaching experience, that is, Careers 4 and 5 teachers, know how to use their time and how students think; instead of pushing students to make decisions in a hurry, these teachers thoroughly instruct them not to rely on information gathered from textbooks or the Internet. One Career 5 teacher (with 30 years of teaching experience) who filled in the free response section of the questionnaire stated, "When I do not get the expected experimental results, I do not immediately show the students the results in the textbook but let them think for themselves about whether they should do the experiment again." This representative response suggests that teachers with longer teaching careers carefully teach critical thinking. Finally, a detailed analysis of the results for "emphasis on objectivity" (Table 10) shows that the mean scores were significantly higher for Careers 4 and 5 teachers than for Career 1 teachers. The mean of the scores was also significantly higher for Career 4 teachers than for Career 3 teachers. These results are generally consistent with the results for "emphasis on demonstrability" and "healthy skepticism." The results suggest that teaching students to be objective and draw conclusions solely from the results obtained requires a high level of teaching skills; thus, teachers with short teaching careers may not achieve this sufficiently. By contrast, teachers with long teaching careers provide detailed instruction using skills acquired through extensive lesson study experience and training sessions organized by the MEXT and other organizations, and this is linked to their teaching of critical thinking. It is unknown why teachers with more than 10 years of teaching experience were at the same level as teachers with shorter careers, and this point needs to be analyzed in more detail.

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Regarding the causal relationships among the factors related to instruction, the results (Figure 1 and Table 11) indicate that the more teachers taught their students to experiment and clarify facts—even if the students knew the laws being tested or the results were obvious without experimentation—the more objective they were in their attitude toward data interpretation. In addition, the more teachers taught their students to interpret data objectively, the more they taught their students not to draw conclusions when they could not obtain sufficient evidence to guarantee objectivity. This indicates that in science classes, teachers provide a series of lessons in which students themselves conduct experiments, collect sufficient data to establish objectivity, and draw conclusions based on the data. Conversely, teachers who did not provide this series of lessons indicated that they did not provide sufficient "emphasis on evidence." Thus, an "emphasis on demonstrability" may improve "emphasis on evidence" in instruction. However, since the study participants were not informed that the survey was about teaching critical thinking, they may have been teaching with an "emphasis on demonstrability" without being aware that they were teaching critical thinking. Encouraging teacher awareness could further enhance the effectiveness of "emphasis on evidence" instruction. In addition, the more teachers instructed students to consider whether there were any oversights or alternative methods, the more students learned to suspend their judgment before interpreting the data or drawing conclusions and to make evidence-focused final judgments. This kind of "multifaceted thinking" is an important factor in improving "emphasis on evidence" as well as "emphasis on demonstrability." Beyer (1987) indicated the importance of direct instruction in critical thinking as a kind of skill and that teachers' intentional instruction can improve students' critical thinking.

Conclusions and Implications

Despite extensive research on critical thinking in the field of science education for more than 50 years, and progress in measuring students' critical thinking and proposing effective teaching methods based on this research, research and analysis on how teachers teach at present have been insufficient. Toward filling this gap, the researcher sought to determine what Japanese science teachers do to acquire critical thinking in their students, whether their teaching skills differ by teaching career length, and what causal relationships exist among the instruction-related factors.

The survey revealed that Japanese science teachers taught the following elements of critical thinking: "emphasis on demonstrability" and "healthy skepticism." However, they did not necessarily teach critical thinking intentionally, and it is possible that they were teaching it unintentionally. This point needs to be investigated further. In addition, teachers did not adequately teach "emphasis on evidence." Regarding differences that arise from the length of teaching careers, teachers with longer teaching careers tended to provide more careful guidance on "emphasis on demonstrability," "healthy skepticism," and "emphasis on objectivity" than those with shorter teaching careers. Regarding "emphasis on evidence," for which teachers' lack of guidance was evident, and "emphasis on demonstrability" and "multifaceted thinking," had a strong influence. In other words, the more teachers taught "emphasis on demonstrability" and "multifaceted thinking," the more they taught "emphasis on evidence." As such, the key to promoting the teaching of "emphasis on evidence" is teaching "emphasis on demonstrability" and "multifaceted thinking," and it is considered effective for teachers to be aware of and intentional about these aspects of their teaching. The findings reported above provide teachers with useful information.

Based on the above, this study makes three recommendations. First, science teachers should be taught the importance of teaching critical thinking to students from an early stage of their pre-service teacher education. More importantly, they should be specifically taught how to teach critical thinking through science lessons. In addition, for in-service teacher education, MEXT and the Board of Education should prepare a training system to support the teaching of critical thinking, especially for newer teachers, in addition to in-school lesson studies. Furthermore, in future studies, researchers should not examine teachers' critical thinking teaching skills and students' critical thinking skill growth separately; rather, they should examine and study the two in relation to one another. Establishing respective critical thinking teaching programs for pre-service and in-service teachers would be significant in developing students' critical thinking skills. In addition, a long-term teaching program connecting these programs is unprecedented in the world and is expected to contribute to science education in the future.

This research has some limitations. Interaction with others is thought to play an important role in the workings of students' critical thinking. However, questions about interaction during instruction, such as discussions

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with others, were not included in the questionnaire used in this study. Thus, future studies should focus on instruction on interaction with others and analyze this aspect in detail. In addition, this study investigated the teachers' teaching conditions using only a questionnaire, which alone is not sufficient; interviews with teachers and students, as well as classroom observations and recordings, should be conducted to collect more information for a more detailed analysis. Furthermore, there is a need to increase the sample size of teachers and conduct research in countries other than Japan, as the results cannot be generalized.

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