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CULTIVATION OF A CRITICAL THINKING DISPOSITION AND INQUIRY SKILLS AMONG HIGH SCHOOL STUDENTS

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Summary

The project described in this report examined the effects of critical thinking instruction and project-based inquiry learning on high school students' critical thinking disposition, inquiry skills, learning competence, and self-efficacy in science courses. One thousand 10th- to 12th-grade students of a Super Science High School in Japan participated in the study. The curricula in this school are constructed using a mixed approach regarding critical thinking: a general approach to critical thinking instruction and practice in special classes is combined with an infusion approach in each subject (e.g., critical-logical thinking instruction in STEM) as well as an immersion approach in cooperative inquiry and project-based learning. The results of three studies show that these learning activities are able to improve students' critical thinking disposition and inquiry skills.

Introduction

Middle school education in Japan has concentrated on cultivating subject knowledge and skills, rather than thinking skills. However, international educational reform movements from about the year 2000 (e.g., OECD, ATC21S [Assessment and Teaching of 21st-Century Skills], and Partnership for 21st-Century Skills in the US [P21]) have been emphasizing the cultivation of generic skills. Critical thinking is considered as one of the most crucial skills among these generic skills.

Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) launched educational reforms in 2002 in response to globalization and the country's shift to a knowledge-based society. To promote science education

to develop students' abilities in STEM (Science, Technology, Engineering, and Math) as well as their generic skills (e.g., critical thinking, creativity, communication, and collaboration), MEXT has designated about 200 high schools throughout Japan as Super Science High Schools (SSH). SSHs are upper secondary education institutions that focus on science and math, and receive support from the Japan Science and Technology Agency (JST) (JST, 2011; MEXT, 2003) (Figure 17.1). SSHs develop enriched curriculum and teaching methods and materials on science and mathematics in cooperation with universities and research institutes. The educational programs of these schools include inquiry-based learning, advanced STEM classes, English for use in scientific contexts, international learning activities with foreign high schools and universities, special programs conducted in cooperation with universities and academic institutions, research activities using regional characteristics to promote students' critical thinking skills, creativity with high-level abilities in STEM, and global mindsets for developing next-generation human resources in science and technology. High schools that apply to be designed as SSH are required to present their curriculum and a five-year plan in their applications.

FIGURE 17.1 Collaborative relationship of Super Science High Schools (SSHs) (Japan Science and Technology Agency (JST), 2011).

The budget for each SSH is about US\$140,000 per year. The acceptance rate varies between 22% and 74% according to fluctuations in the number of schools that apply each year. Surveys of graduates of SSH show that the rate at which SSH students enter higher education in the natural sciences is about two to three times higher than the national average (Kobayashi, Araki, & Ono, 2015).

This paper concentrates on critical thinking, which has been studied since at least the 1910s when John Dewey first published his landmark book, *How We Think* (1910). Based on Dewey's conceptualization, critical thinking is analogous to metacognition or thinking about one's thinking. Critical thinking is (a) reasonable and reflective thinking focused on deciding what to believe or do (Ennis, 1987); (b) logical, and unbiased thought based on criteria and evidence (Kusumi, 2018b); and (c) skilled and active interpretation and evaluation of observations and communications, information, and argumentation (Fisher & Scriven, 1997).

Critical thinking is divided into two parts: cognitive and affective components (e.g., Ennis, 1987). First, cognitive components are skills and knowledge, especially domain-general skills and knowledge; for example, clarification, evaluation of the reliability of information, inference, and decision-making. Note that in contrast, examples of domain specific knowledge include scientific methodology and knowledge for understanding health information. Second, the affective components of critical thinking are disposition and attitude. Critical thinking is not conducted using one's cognitive abilities alone; disposition is also important. For example, critical thinking disposition is an important factor in being able to draw correct conclusions from contrary pieces of evidence and avoid succumbing to the influence of belief biases (Hirayama & Kusumi, 2004).

It is important to cultivate critical thinking skills and disposition through a systematic curriculum that utilizes a mixed approach (Ennis, 1987), combining a general approach (e.g., general critical thinking instruction in special classes) with infusion (e.g., critical thinking instruction in STEM subjects) and immersive approaches (e.g., project-based learning). Metanalyses of the teaching of critical thinking indicate that the mixed approach significantly outperforms all other single approaches (Abrami et al., 2008).

We conducted three surveys concerning critical thinking skills, disposition, and learning competence at a Super Science High School, which is a top-ranked public high school located in the Kansai region in Japan.

This high school aims to arouse students' intellectual curiosity and cultivate their critical thinking skills through its educational programs (Zeze High School, 2018). Students participate in a project-based learning class (see [Tables 17.1](#) and [17.2](#)), special classes (e.g., humanity and social science, environmental science, life science, and medical science) presented by Kyoto University and Shiga University of Medical Science, international learning activities (e.g., visiting high schools in the United States and UK), and regular classes (e.g., STEM, English for use in scientific contexts, and history) based on systematic curricula that foster students' logical-critical thinking skills, international awareness, and sense of curiosity.

TABLE 17.1 Project-based learning class (one or two hours per week) for 10th- to 12th-grade students**Objectives**

1. Cultivating students' dispositions on learning and thinking, active and creative problem solving and inquiry skills, and encouraging students to reflect on their lives and careers.
2. Cultivating students' competence and ability to find and solve problems, learn, and make decisions.

10th-grade students

First semester

Cultivating individual inquiry skills through lectures and individual project-based learning

- a. Lectures and practice on problem finding, inquiry learning, critical thinking, and ICT skills (e.g., searching for information using the Internet) for students' research projects.
- b. Conducting research projects individually (identifying research questions, conducting research, and writing papers).

Second semester

Cultivating individual inquiry skills through lectures, reflection on students' projects and project-based learning in groups.

- a. Lectures and project-based learning involving ICT skills (e.g., computation using Excel) for the group project.
- b. Reflecting on individual research projects in a group (reading fellow group members' reports and providing critical comments).
- c. Conducting a group research project (identifying a research question, conducting research).

Third Semester

Presenting the outcomes of the group projects and engaging in a critical discussion.

- a. Writing reports and posters.
- b. Presenting posters and conducting discussions critically.

11th-grade students

First semester

Cultivating individual inquiry skills through lectures and individual project-based learning.

- a. Lectures and practice on inquiry learning, critical thinking, presenting posters, and writing papers.
- b. Conducting individual research projects (identifying research questions, conducting research, and writing papers).
- c. Developing academic English skills for preparing a poster presentation in English.

Second semester

Cultivating individual inquiry and critical skills through lectures, reflections on students' projects, and group project-based learning.

- a. Lectures and project-based learning in groups.
- b. Reflecting on students' research projects in a group (reading fellow group members' reports and providing critical comments).
- c. Conducting a group research project using ICT (e.g., conducting questionnaire, data analysis).
- d. Preparing a poster presentation in English in the school and presenting a poster at a university in the US (ten-minute presentation and five-minute discussion).

(continued)

TABLE 17.1 Project-based learning class (one or two hours per week) for 10th- to 12th-grade students (*Continued*)

Third Semester

Conducting a final individual research project.

- a. Planning and conducting the final research project.
- b. Reflecting on progress on research projects.

12th-grade students

First semester

Cultivating individual inquiry and critical skills through project-based learning.

- a. Lecture and practice on oral presentations using Power Point and writing papers.
- b. Continuing the final research project (conducting research and writing a paper).
- c. Presenting papers in an oral session in school.

Second semester

Cultivating individual inquiry and critical skills by preparing for university studies.

- a. Researching admissions policies and preparing studies for students' chosen universities.
- b. Presenting and discussing the results of research in the group.

TABLE 17.2 Process of project-based learning in the SSH

1. Planning research project
 - i. Idea generation (e.g., generating topics of interest using 10×10 cell tables)
 - ii. Clustering ideas (e.g., sorting the 100 ideas-cards into several piles)
 - iii. Clarifying research topics (e.g., naming the piles of clustered topics)
 - iv. Reviewing previous research
2. Collecting empirical evidence
 - i. Selecting a research method and planning
 - ii. Conducting an experiment
 - iii. Analyzing data
3. Presenting results
 - i. Writing a paper in Japanese
 - ii. Comments on the paper by peers in small groups
 - iii. Preparing posters and practicing presentations in a group
 - iv. Preparing and practicing oral presentations in Japanese and in English

Examples of research projects

Changes in birds' bills due to environmental changes

Production of antibiotics by soil bacteria

Ecosystem changes related to water pollution

Is it possible to stop desertification?

The benefits and harms of the volcano

An evaluation of "complexity" via fractal dimension: An illustration of stone walls

Relationship between superabsorbent polymers and deodorization

An analysis of bubble transformation

Research on coil with Gauss accelerator

This school uses a mixed approach to teach critical thinking (Ennis, 1989), combining a general approach (e.g., critical thinking instruction and practice in special classes), an infusion approach in each subject (e.g., critical-logical thinking instruction in STEM and English for use in scientific contexts), and an immersion approach through project-based learning (Krajcik & Shin, 2014; Thomas, 2000). Metanalyses have indicated that mixed-approach and project-based learning improves students' critical thinking skills (Abrami et al., 2008).

We had previously explored the relationships between critical thinking disposition, reflective predisposition, and perceived academic competence in elementary school students (5th- and 6th-graders) and junior high school students (7th–9th graders) in Japan using a two-wave questionnaire survey (Kusumi, Murase, & Takeda, 2011). A simultaneous path analysis revealed that during each wave, (i) reflective predisposition influenced critical thinking disposition in general (CT-G); (ii) critical thinking disposition in general (CT-G) affected critical thinking disposition during study in class (CT-S); and (iii) critical thinking disposition during study (CT-S) affected perceived academic competence. However, there are few studies that examine the kinds of learning activities that might improve critical thinking in high school. Abrami et al. (2008) reviewed 158 empirical studies on the teaching of critical thinking skills in post-elementary education published between 1960 and 2005. There were only eight studies (5%) concerning high school students (16–18 years of age) and their effect size (g) was .10 ($SE = .06$, 95% CI $[-.03, .22]$, $Z = 1.56$, ns). In contrast, the number of studies concerning undergraduate postsecondary students was 80 (51%) and the effect size (g) was .25 ($SE = .02$, 95% CI $[.21, .29]$, $Z = 12.30$, $p < .05$). Therefore, in the investigations we report here, we decided to explore critical thinking education at the high school level.

In the following section, we will describe methods of our three surveys conducted in the Super Science High School that, among other things, aimed at improving critical thinking disposition and inquiry learning skills in its students.

Methods employed in the SSH to cultivate critical thinking

The curriculum in the school consists of three main parts: (1) learning in regular classes (e.g., learning STEM knowledge and research methods), (2) project-based learning classes, and (3) visiting research institutions and universities in Japan and the United States (e.g., attending lectures and seminars, and presenting papers).

The project-based learning class was divided into three parts (Table 17.1, Table 17.2): (i) improving inquiry and critical thinking skills through lectures and practice (the author conducted a lecture on critical thinking for students in the 10th- and 11th-grades [Table 17.3] as part of this section); (ii) conducting research projects individually, writing papers, and engaging in discussions in groups of four students; and (iii) conducting advanced group research projects,

TABLE 17.3 Content of lecture on critical thinking

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1. Definition and importance of critical thinking (e.g., Ennis, 1987)
 2. Critical thinking skills for inquiry learning
 - Clarification, basis of inference, inference (induction, deduction, analogy, value judgment), behavioral decision (career decision) based on Ennis's (1987) framework
 - Practice concerning scientific literacy (e.g., hidden assumptions, 2×2 matrix, control group, the reliability of scientific evidence, credibility of information, over-generalization)
 3. Critical thinking disposition (e.g., Kusumi, Murase, & Takeda, 2011)
 4. How to cultivate your critical thinking skills
-

presenting posters in Japanese and English, and writing papers in Japanese (Zeze High School, 2010).

Evidence for the effectiveness of the approach used in the high school

Study 1: The effect of learning activities on critical thinking and other skills: Cross-sectional data

This study addressed three research questions: (i) Are there any improvements in critical thinking disposition by grade? (ii) What types of learning activities promote critical thinking disposition? (iii) What factors affect learning competence and satisfaction in school?

Method

We conducted a questionnaire survey of all students of the SSH. There were 1,141 students (629 boys, 512 girls), comprised of 371 10th-graders (187 boys, 184 girls), 395 11th-graders (243 boys, 152 girls), and 375 12th-graders (199 boys, 176 girls). The questionnaire had six parts: (a) Critical thinking disposition in general (CT-G: 10 items) and during study (CT-S: 10 items [Kusumi, Murase, & Takeda, 2011]). The CT-G scale is a modified version of Hirayama and Kusumi's (2004) critical thinking scale (Manalo, Kusumi, Koyasu, Michita, & Tanaka, 2013) that is based on the California Critical Thinking Disposition Inventory (CCTDI; Facione & Facione, 1992). (b) Reflective-impulsive scale (5 items) (Takigiku & Sakamoto, 1991). (c) Learning competence scale (10 items, 4-point scale) (Sakurai, 1992). (d) Participation in learning activities (7 items, 6-point scale, e.g., a project-based learning class, club activity). (e) Learning time at home and in a study hall (time spent per day). (f) Satisfaction with school life (5-point scale).

Results and discussion

The critical thinking disposition in general scale (CT-G) items are divided into four factors: inquisitiveness (e.g., search for multiple options and consider all

FIGURE 17.2 Percentage of responses for critical thinking disposition in general (CT-G) (Study 1).

situations with open-mindedness), objectivity (e.g., use reliable sources of information), reliance on evidence (e.g., decide based on evidence and reason), and logical thinking disposition (e.g., seek clear assertions and reasons). Figure 17.2 shows the percentage of “agree” and “mildly agree” responses in the self-evaluation of critical thinking disposition in general. Examples are, “I want to meet different kinds of people, and to learn a lot from them” (inquisitiveness), “studying new things all my life would be wonderful” (inquisitiveness), “I try to make unbiased judgments” (objectivity) and “I try to think from different perspectives” (objectivity). These responses and the total mean score increased with the number of years spent in school. The differences among 10th-, 11th-, and 12th-graders were significant ($M_s = 3.54, 3.73, 3.83$, respectively; $F = 23.0, p < .001$).

The critical thinking disposition during study (CT-S) items are divided into three factors: elaboration, thinking in class, and actively listening to others’ opinions. Figure 17.3 shows the percentage of “agree” and “mildly agree” responses in the self-evaluation of critical thinking disposition during study. For example, “I try to relate new information to everyday life and society” (elaboration),

FIGURE 17.3 Percentage of responses for critical thinking disposition during study (CT-S) (Study 1).

“I am thinking of what the important point in the topic is” (thinking in class), and “I am checking the bias and prejudice in others’ opinions” (active listening), increased with the number of years spent in school. The total mean score increased significantly between 10–12th grades in school ($M_s = 2.78, 2.80, 3.02$, respectively; $F = 14.5, p < .001$).

FIGURE 17.4 The effects of learning activity on learning competence via critical thinking. Standardized coefficients for path analysis (Study 1).

Figure 17.4 shows the effects of learning activity on learning competence via critical thinking. All path coefficients are significant. The application of path analysis to the above data revealed the following: (i) Students' reflectiveness affected their critical thinking disposition in general (CT-G). Highly reflective students committed more to engaging in the project-based learning and the special classes provided by Kyoto University, and then, developed their critical thinking disposition in general (CT-G). (ii) Students' critical thinking disposition in general (CT-G) strongly affected their critical thinking disposition during study (CT-S), which was affected by learning times (amount) at home and in the study hall. (iii) Critical thinking disposition during study (CT-S) affected learning competence. (iv) Students' satisfaction with school was affected by learning competence, commitment to school festivals, the project-based learning, and club activities.

These results indicate that: (i) critical thinking disposition in general (CT-G) and during study in class (CT-S) improved by grade level, (ii) project-based learning activities and the special classes by Kyoto University promoted critical thinking disposition (CT-G, CT-S), (iii) critical thinking disposition during study (CT-S) affected learning competence, and school activities then affected satisfaction with school.

We found critical thinking disposition by grade—using cross-sectional data—increased among students in the school. In the next study, we conducted a two-wave questionnaire study to explore more precisely the causal effect of the project-based learning program on critical thinking disposition and inquiry

skills development. We also explored the effects of critical thinking skills on inquiry learning skills, self-efficacy and interest in science, and learning competencies.

Study 2: The effect of critical thinking and other skills: Two-wave data

We concentrated on inquiry learning in Study 2 and developed an inquiry learning skills scale for this study. This study addressed two research questions: (i) Do critical thinking disposition, inquiry learning skills, and other variables improve from the beginning to the end of the school year by learning activities? (ii) What factors affect learning competence and satisfaction at school?

Method

We conducted a two-wave questionnaire survey with 10th- and 11th-grade students of the SSH at the beginning and at the end of the school year. There were 837 students (457 boys, 361 girls, 19 undetermined [did not respond to the question about gender]), comprised of 439 10th-graders (250 boys, 176 girls, 13 undetermined) and 398 11th-graders (207 boys, 185 girls, 6 undetermined).

The questionnaire had six parts: (a) Inquiry learning skills (11 items, 5-point scale, Cronbach's α s = .80, .82), which are based on three phases of inquiry learning: planning of research project; collecting empirical evidence; and presentation of results). (b) Critical thinking disposition in general (10 items, α s = .78, .78) and during study (10 items, α s = .78, .81) (Kusumi, Murase, & Takeda, 2011). (c) Reflective-impulsive scale (5 items, α s = .70, .71) (Takigiku & Sakamoto, 1991). Both (b) and (c) were the same as in Study 1. (d) Learning competence scale (10 items, 4-point scale, α s = .78, .78) (Sakurai, 1992). (e) Self-efficacy in science (4 items, 4-point scale, α s = .68, .76, e.g., identify the better of two explanations for the formation of acid rain). (f) Interest in science (5 items, 4-point scale, α s = .84, .85, e.g., "I enjoy acquiring new knowledge in natural science"). Both (e) and (f) were used in PISA 2006 (Programme for International Student Assessment, 2007).

Results and discussion

As previously noted, the inquiry learning skills scale items comprised the three phases of planning research, collecting empirical evidence, and presenting results. Figure 17.5 shows the percentage of responses on the 5-point scale in students' self-evaluation of their inquiry learning skills. The percentage of "agree" and "mildly agree" of all items of inquiry learning skills increased between Time 1 and Time 2. For example, "I define my research topic based on my

FIGURE 17.5 Percentage of responses for inquiry learning skills at time 1 and time 2 (Study 2).

interests and develop a precise research question” (planning research and presenting results phases) (from Time 1 [agree + mildly agree] 28% (10th grade) and 31% (11th grade) to Time 2 [agree + mildly agree] 55% (10th grade) and 51% (11th grade), respectively); “I test hypotheses based on empirical evidence” (collecting empirical evidence phase) (from 30%, 42% to 63%, 51%); “I write essays logically based on evidence” (presenting results phase) (from 27%, 34% to 56%, 34%) increased from time 1 (the beginning of the school year) to time 2 (the end of the school year).

Table 17.4 indicates that the mean scores in the three subscales of inquiry learning skills (planning research; collecting empirical evidence; and presenting results) in 10th- and 11th- grade students increased significantly from time 1 to time 2.

Furthermore, the critical thinking disposition in general and during study in class, self-efficacy and interest in science, and learning competence in the 10th and 11th grades also increased significantly from time 1 to time 2.

Figure 17.6 shows the effects of critical thinking disposition on learning competence via inquiry skills in Time 1 and Time 2. The path analysis of two-wave data results indicates that: (a) reflectiveness affected critical thinking disposition in general (CT-G) and during study in class (CT-S); (b) CT-G affected CT-S and inquiry skills; (c) CT-S affected inquiry skills, learning competence, interest, and self-efficacy in science; (d) CT-S and inquiry skills affected self-efficacy in

TABLE 17.4 Means (SDs) for critical thinking and inquiry skills and outcome measures in time 1 and time 2 (Study 2)

Scale	Grade	Time 1		Time 2		
		M	SD	M	SD	
Reflectiveness ^a	10th ^c	3.14	(.74)	3.17	(.71)	0.75
	11th ^d	3.17	(.71)	3.24	(.72)	1.92 +
Critical thinking disposition in general ^a (CT-G)	10th	3.66	(.55)	3.85	(.51)	7.57 **
	11th	3.67	(.54)	3.80	(.50)	5.28 **
Critical thinking disposition during study ^a (CT-S)	10th	3.10	(.58)	3.15	(.63)	1.59
	11th	2.94	(.55)	2.98	(.57)	1.11
Inquiry skills ^a	10th	3.16	(.57)	3.57	(.51)	14.76 **
	11th	3.22	(.53)	3.41	(.53)	6.64 **
Planning ^a	10th	2.97	(.79)	3.41	(.68)	10.19 **
	11th	3.05	(.68)	3.30	(.69)	5.43 **
Empirical ^a	10th	3.29	(.76)	3.68	(.68)	9.20 **
	11th	3.35	(.67)	3.50	(.71)	3.44 **
Presentation ^a	10th	3.11	(.76)	3.58	(.70)	12.16 **
	11th	3.22	(.71)	3.41	(.66)	4.56 **
Self-efficacy in science ^b	10th	2.53	(.50)	2.70	(.51)	6.80 **
	11th	2.57	(.50)	2.70	(.52)	4.39 **
Interest in science ^b	10th	3.10	(.56)	3.22	(.54)	4.54 **
	11th	2.97	(.57)	3.06	(.59)	2.93 **
Learning competence ^b	10th	2.44	(.51)	2.52	(.56)	3.31 **
	11th	2.36	(.55)	2.47	(.57)	4.54 **

Note. ^a5-point scale, ^b4-point scale, ^c $n = 396$, ^d $n = 291$, ** $p < .01$, + $p < .10$.

science; (e) self-efficacy affected interest in science; (f) learning competence was affected by CT-S and interest in science; (g) the variables in Time 1 strongly affected the same variables in Time 2; (h) the causal relationship in Time 1 was structurally mapped onto Time 2; and (i) the differences between the 10th- and 11th-grade students in coefficients were small.

Using two-wave data of 10th- and 11th-grade students, we found improvements in critical thinking disposition, inquiry-learning skills, self-efficacy and interest in science, and in learning competence from the beginning to the end of the school year. We also discovered the effects of critical thinking disposition on study in inquiry learning skills, self-efficacy and interest in science, and learning competencies.

In the next study, we explored more precisely the effect of the critical thinking lecture on the students' image of critical thinking and their critical thinking disposition in general and in writing.

Study 3: The effect of the critical thinking lecture on the image of critical thinking

We concentrated on the effects of the critical thinking lecture on students' image of critical thinking in Study 3. "Critical thinking" is often misunderstood by

FIGURE 17.6 The effect of critical thinking disposition on learning competence via inquiry skills. Standardized coefficients for path analysis using two-wave data. CT = Critical thinking.

students; critics of critical thinking may claim that it is aggressive and confrontational rather than collegial and collaborative (Bailin & Siegel, 2003). Students tend to have a negative image of critical thinking and critical thinkers, believing that they must be aggressive and uncooperative. For example, Japanese students conceive of critical thinkers as unamicable people (Hirooka, Ogawa, & Motoyoshi, 2000). Rather than being aggressive, however, critical thinking is in fact cooperative. We instruct students that critical thinking is logical, reflective, and cooperative thinking that they can use in their studies and everyday life through cooperative project-based learning, which is not confrontational.

We also focused on writing, which is an important inquiry learning skill in the research presentation phase. Writing is important for developing and assessing critical thinking (Wade, 1995). Students are required to write a report on their research project at the end of both the spring and fall semesters. This third study addressed two research questions: (i) Do lectures on critical thinking change students' conception of "critical thinking" from negative to positive? (ii) Do logical and cooperative images of critical thinking affect students' critical thinking disposition in general and in their writing?

Method

We conducted a one-hour lecture on critical thinking for project-based learning (e.g., definition, purpose, skills, disposition, and practices) and a pre-lecture and

FIGURE 17.7 The change of meaning in “Critical thinking”: Before and after the lecture using semantic differential scale (Study 3) ($N = 424$).

post-lecture questionnaire survey of 424 10th-grade students (247 boys, 177 girls) of the high school. These students were participants in Study 2.

The questionnaire had three parts: (a) semantic differential scale (seven pairs of bipolar adjectives, 7-point scale; e.g., *warm-cold*, *aggressive-non aggressive*, *logical-illogical*, see Figure 17.7); (b) critical thinking disposition as displayed in their own writing (nine items, Stapleton, 2002, e.g., “It is important to state my opinion clearly, even if the topic is controversial,” “It is not important to mention the opinion of those who disagree with me as long as I write my own opinion clearly”) ($\alpha = .58$); (c) critical thinking disposition in general (10 items, $\alpha_s = .78, .78$) and during study (ten items, $\alpha_s = .78, .81$) (Kusumi, Murase, & Takeda, 2011), as used in Study 1.

Results and discussion

Figure 17.7 shows the effect of the critical thinking lecture on the students’ image of critical thinking. The profiles indicate the mean ratings of “critical thinking” from before (left) to after the lecture (right) based on the mean ratings of the semantic differential scale.

The mean scores of “logical” and “practical” were changed from “*somewhat...*” to “*quite...*” (Cohen’s $d_s = .53, .97$). The mean score of “like-dislike” was changed from neutral to “*somewhat like*” ($d = .86$). Conversely, the mean score of “non-cooperative,” “cold,” “hard,” and “aggressive” were changed from “*somewhat (negative)*” to “*neutral*” ($d_s = .97, 1.22, .89, .51$).

The bipolar items were divided into two subscales “logical-practical image” (2 items) and “cooperative image” (4 items), which were indicated in the two dotted line boxes in Figure 17.7. These two subscales were based on factor analysis (method of maximum likelihood, Promax rotation) which extracted the two factors (62.6% of the variance).

TABLE 17.5 Correlations for the image of critical thinking and critical thinking disposition as a function of the lecture (Study 3)

Image of Critical thinking (CT)	After lecture ^a		End of the school year ^b		
	CT disposition in writing (CT-W)	CT disposition in general (CT-G1)	CT disposition in general (CT-G2)	CT disposition during study (CT-S)	Inquiry skills
Before lecture					
Logical image (L1)	.22***	.22***	.22***	.13*	.08
Cooperative image (C1)	-.04	.02	.00	-.04	-.16**
After lecture					
Logical image (L2)	.37***	.29***	.26***	.20***	.14**
Cooperative image (C2)	.10	.08	.03	.02	.01
Difference					
Logical image (L2-L1)	.14**	.06	.03	.07	.06
Cooperative image (C2-C1)	.11*	.04	.02	.05	.14**

Note. ^aN = 389–401, ^bN = 356–366, **p* < .05, ***p* < .01, ****p* < .001.

Table 17.5 shows the correlations between the two images of critical thinking (before and after the lecture) and critical thinking (CT) disposition in writing (CT-W) and in general (CT-G1). The correlation between the logical-practical image of CT (L1,L2) and CT disposition in writing (CT-W) (before .22, after .37) and in general (CT-G1) (before .22, after .29) increased after the lecture. Differences in the logical-practical image before and after the lecture (L1, L2) were slightly correlated with CT disposition in writing (CT-W) (.14). Concerning the long-term effect (four-month interval), the logical-practical image after the lecture (L2) was correlated with CT disposition in general (CT-G1) (.29), during study (CT-S) (.20), and at the end of the school year (CT-G2)(.26). These correlations were higher than the logical-practical image before the lecture (L1).

Figure 17.8 indicates the causal effects of the logical-practical image of critical thinking (CT) after the lecture on CT disposition in general and in writing. CT disposition in general (CT-G1) and in writing's (CT-W) effect on CT disposition in general (CT-G2) at the end of the school year are then depicted. CT disposition in general after the lecture (CT-G1) also affected CT disposition during study (CT-S) and inquiry skills. The image of CT before the lecture (L1) affected the image after the lecture (L2) but did not directly affect CT disposition at the end of the school year (CT-G2, CT-S). Conversely, the cooperative image of CT did not affect CT disposition in general and in writing. The reason for this is that the cooperative image of CT

FIGURE 17.8 The effect of the logical-practical image of critical thinking after the lecture (L2) on CT disposition in general (CT-G1) and in writing (CT-W). Standardized coefficients for path analysis using pre- and post-lecture and data four months later. CT = Critical thinking.

was related to CT disposition during discussion and in group work, but not in writing and other individual situations.

Figure 17.9 shows the test of mediation of the logical-practical image of CT after the lecture (L2). The mediation occurs when the significant relationship between the logical-practical image of critical thinking after the lecture (L1) and the dependent variables (Figure 17.9a: CT-G1; Figure 17.9b: CT-W), reliably decrease. Confirmation was found for the mediator role of L2: both the mediation effect (range from .10 to .19, and from .06 to .18 not including zero in the 95% CI) and the Sobel test ($ps < .001$) were significant.

These results indicate that the lecture enhanced the perception of the logical-practical aspects of “critical thinking.” Conversely, the meaning of the aggressive aspects was decreased by the lecture. The image of “critical thinking” became an image of something more logical-practical and cooperative. The logical-practical image of critical thinking after the lecture affected critical thinking disposition in general and in writing.

General discussion and conclusion: Cultivating critical thinking dispositions and inquiry skills in high school education

In this chapter, we examined the effects of learning activities on cultivating critical thinking disposition and inquiry skills in a high school. We have described three studies using cross-sectional data of 10th- to 12th-grade students, two-wave data of 10th- and 11th-grade students, and pre-post lecture data of 10th-grade students. The three main results are reported in the following paragraphs.

FIGURE 17.9 Results from mediation analysis of the logical-practical image of critical thinking (CT) after the lecture (L2) on the effects before the lecture (L1) for CT disposition a) in general (CT-G1) and b) in writing (CT-W). Standardized coefficients are as shown. $^{***}p < .001$, $^*p < .05$ ($N = 453$).

First, we found that (i) critical thinking disposition in general and during study improved by grade, (ii) various learning activities (e.g., project-based learning) promoted critical thinking disposition, and, (iii) the critical thinking disposition during study affected learning competence.

Second, we found that critical thinking disposition, inquiry-learning skills, self-efficacy and interest in science, and learning competence improved from the beginning to the end of the school year. We also determined the effects of critical thinking disposition during study on inquiry learning skills, self-efficacy and interest in science, and learning competencies.

Third, we discovered that the logical-practical image of critical thinking was enhanced after the lecture, while the aggressive image of it decreased. The logical-practical image of critical thinking after the lecture affected critical thinking disposition in general and in writing.

This enhancement of the logical-practical image of critical thinking is most likely due to the mixed approach to the teaching of critical thinking that was used, combining a general approach (e.g., critical thinking practice in special class), an infusion approach in each subject (e.g., critical-logical thinking instruction

in STEM, English for preparing presentations), and the immersion approach in cooperative inquiry and project-based learning (e.g., Krajcik & Shin, 2014).

These results are consistent with the findings of meta-analytic studies that have indicated that a mixed approach (e.g., Abrami et al., 2008), project-based inquiry learning, and collaborative learning (e.g., Ten Dam & Volman, 2004) improve students' critical thinking disposition and abilities. The three components of the mixed approach used to cultivate students' critical thinking disposition and inquiry skills are (i) the general approach to critical thinking instruction and practice utilizing group work, in which students reflect on their own thinking by interacting with group members; (ii) the infusion approach in each subject (e.g., critical-logical thinking instruction in STEM, including scientific research methods and knowledge), which promotes students' critical thinking disposition and inquiry skills in STEM for scientific research; and (iii) the immersion approach in project-based learning (e.g., Barron, & Darling-Hammond, 2010; Krajcik & Shin, 2014; Thomas, 2000), which promotes students' critical thinking dispositions and inquiry skills for problem solving in science and everyday life. Students also acquired cooperative critical thinking disposition and inquiry skills by preparing presentations and papers for group projects.

Previous studies on inquiry-based and cooperative learning in undergraduates (e.g., Ahern-Rindell, 1998; Gokhale, 1995) as well as in elementary and high school students (e.g., Adams & Hamm, 1996) have also indicated the effectiveness of cultivating students' critical thinking. Therefore, these essential elements in the instructional method (the mixed approach combining a critical thinking practice, an infusion approach in each subject, and an immersion approach in project-based learning) can be applied to other high schools, junior high schools, and elementary schools in Japan and in other countries.

There are several constraints on conducting surveys, engaging in educational interventions, and collecting performance data in high schools. These constraints have placed limitations on this study that will need to be addressed in future work. First, students' critical thinking disposition and inquiry learning skills increased over their years spent in school. However, this has not been compared with a control group. Second, students' critical thinking dispositions affected their learning competence, self-efficacy, and interest in science. These results relied only on students' self-reports of their critical thinking disposition and competencies. In future work, students' performance tests, academic grades, achievement tests, and behavior concerning critical thinking dispositions and inquiry skills should be considered.

The following are a few important research questions for future studies.

- Are there any differences in the improvement of critical thinking disposition between the intervention group (e.g., Super Science High Schools) and the control group (e.g., students of non-Super Science High Schools or students in other courses in the same school)? We are conducting this type of comparative study in a different high school, studying a science course and another course (Kusumi, 2018a).

- Can improvements in critical thinking abilities be measured by standardized tests or performance tests? We are developing a standardized critical thinking test (Kusumi, Taira, Hasegawa, 2016) and performance tests using critical questions (Browne & Keely, 2007; Kusumi, 2017).
- Does critical thinking education affect academic achievement (e.g., in STEM and other subjects) via critical thinking disposition and inquiry skills? We are conducting a longitudinal study of this topic using standardized academic achievement tests and academic grades in STEM subjects and inquiry-based learning classes (Kusumi, 2018a).

This chapter described three surveys conducted at the school level. The school in question has an active learning environment using project-based collaborative learning and instruction on cultivating critical thinking and inquiry skills. Through various learning activities, students can improve their critical thinking dispositions and inquiry skills. We believe that the research-oriented characteristics of the school culture and school organization are also important contributors to cultivating students' critical thinking at the school level (e.g., Ten Dam & Volman, 2004).

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