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Exploring the role of a discrepant event in changing the conceptions of evaporation and boiling in elementary school students

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The purpose of this study was to explore how examples used in teaching may influence elementary school students' conceptions of evaporation and boiling. To this end, the examples traditionally used to explain evaporation and boiling in Korean 4th grade science textbooks were analyzed. The functions of these published examples were explanation (empirical recognition, identification, and evidence) and reinforcement (applications). However, few reinforcement functions (such as comparison and supposition) or clarification functions (such as extension and contrast) were employed. The evaporation and boiling conceptions of 41 students in the 4th grade, 55 students in the 5th grade, and 28 students in the 6th grade were surveyed. Many students thought of evaporation phenomena under heating conditions as boiling, and the same phenomena without an obvious source of heating as evaporation. This meant that the presence of heating affected the students' conceptions of evaporation and boiling. In this study, the students were presented with clarifying functional examples that were not included in the textbooks. After exposure to these examples, many students revised their misconceptions and adopted scientific conceptions. Previous studies have argued that students must be able to reason from a microscopic point of view to understand evaporation and boiling phenomena; however, the tested students were able to classify the two different phenomena after experiencing appropriate functional examples.

Introduction

Evaporation and boiling are real-life macroscopic physical processes that can contribute to an understanding of other abstract phenomena such as states of matter, changes of state, conservation of matter, and particle theory (Anderson, 1990; Osborne & Cosgrove, 1983; Stavy, 1990a, 1990b). However, students can have difficulty learning these concepts because the gas state is not easily observed. The various difficulties and misunderstandings of these concepts by elementary school students have been followed over extended periods by a number of researchers (Driver *et al.* 1994; Tytler, 2000; Paik *et al.* 2004; Canpolat, 2006; Fredrickson *et al.* 2006; Varelas *et al.* 2006; Tytler *et al.* 2007).

Once a student adopts a wrong interpretation, it will negatively affect his understanding. For example, many researchers have reported that older students have as many or more misconceptions than younger students (Osborne and Cosgrove, 1983; Hwang and Hwang, 1990; Bar and Travis, 1991). Schmidt *et al.* (2009) showed that German students in grades 11 to 13 had many alternative explanations for boiling. Even though students used evaporation and boiling terminology, their comprehension was different from that of scientists, and they failed to understand basic scientific concepts syntagmatically (Osborne and Cosgrove, 1983). Moreover, pre-service teachers were unable to differentiate between boiling and evaporation (Valanides, 2000). Yalcin (2012) reported that pre-service primary science teachers had an inadequate understanding and some common misunderstandings regarding vaporization. Senocak (2009) revealed that primary school teachers with non-science backgrounds had many misconceptions about boiling phenomena, based on their daily life experiences and an inadequate knowledge of science.

Logical thinking about the conservation of matter and the concept of "air" is important in developing a scientific understanding of evaporation phenomena (Bar and Galili, 1994; Johnson, 1998a, 1998b). Because the concept of air can be made based on a microscopic viewpoint, Tytler *et al.* (2007) asserted that there should be multiple representations related to the molecular view of matter for a student's understanding of evaporation. Moreover, many previous studies have stressed that macroscopic and microscopic representations are important for student understanding (Stavy, 1988; Ainsworth, 1999; Seufert, 2003; Cook *et al.* 2008; Hubber *et al.* 2010; Kirbulut and Beeth, 2013). Yilmaz and Aop (2006) studied the understanding of matter by 8th, 10th, and 11th grade students and found that their reasoning abilities increased by grade, and the grade variable was important to the understanding of matter. Stamovlasis *et al.* (2012) also surveyed previous

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studies related to students' understanding of matter, especially the gaseous state, and insisted that logical thinking, field-dependence/independence, and convergence/divergence played significant roles in the conceptual understanding of physical change.

If students could acquire the skills to think logically from a microscopic point of view, there are many scientific concepts that they could learn successfully. Krnel *et al*. (2003) proposed that students' understanding of concepts was increased by cognition level due to their increasing experience. Although the cognitive structure might change with age, few changes in conception follow without related experiences. Misconceptions formed by life or educational experiences are difficult to change and are continued by school education (Osborne and Cosgrove, 1983).

Two studies have reported the educational effects of students' conception changes (Costu *et al.* 2007, 2010). Investigations of the various preconceptions of college students related to evaporation and boiling suggested the possibility that student conceptions can be changed by instruction. Yalcinkaya and Boz (2015) also insisted that case-based instruction based on conceptual change conditions influenced 10th graders' conceptual understandings. However, not only higher-level students but also elementary school students must understand physical phenomena, although it is difficult to introduce the microscopic point of view to elementary school students. Therefore, other approaches are needed to develop an understanding of evaporation and boiling in these younger pupils.

In Korea, evaporation and boiling concepts are introduced in the 4th grade science curriculum, without a microscopic point of view. The explanations include only the descriptions of the phenomena. Traditionally, evaporation and boiling concepts are introduced with real-life examples in elementary science class. Students develop their conceptions of matter and natural phenomena based on their experiences; these ideas are increasingly refined, until they become valid scientific concepts (Oyehaug and Holt, 2013). However, when the concepts are difficult or abstract, proper teaching strategies are needed for student understanding (Ultay *et al*. 2015). Demonstrations by teachers in the classroom provide concrete examples of abstract concepts, and are potential sources of conceptual change (Bodner, 2001). However, a limited number of demonstrations or examples can cause students to form alternative conceptions.

It is important to distinguish the characteristics of empirical experiences to understand the similarities between phenomena such as evaporation and boiling, which both involve a change from liquid to gas. In Korea, 4th grade students should be able to distinguish between evaporation and boiling concepts, but many difficulties have been reported, even among high school students. Cho and Paik (2004) reported that high school students distinguished between evaporation and boiling based on the presence of heat rather than the appearance of bubbles or the location at which evaporation occurs. If the water was being heated, most students classified the phenomenon as boiling. It seems that the application of heat affects the formation of misconceptions about boiling, because most of the examples of boiling are represented as occurring during heating. Osborne and Cosgrove (1983) and Kruger and Summers (1989) also indicated that many students thought boiling occurred due to heating. Canpolat *et al.* (2006) revealed undergraduate students' misconceptions related to evaporation, in which a liquid must be heated to the boiling point in order to vaporize. These findings suggest that the students' difficulties in learning scientific concepts results from insufficient example representation.

The functions of examples for understanding concepts. According to You (2012), examples can be classified into three functions: explanation, reinforcement, and clarification. These functions can be further subdivided: the explanation function comprises empirical recognition, identification, and evidence; the reinforcement function consists of application, comparison, and supposition; and the clarification function is divided into extension and contrast.

"Empirical recognition," one of the explanation functions, is formed by students' surrounding experience. "Identification" is a property that must be included for students' understanding, and "evidence" is necessary to confirm the property. "Application," one of the reinforcement functions, strengthens conceptual understanding by adopting the properties of the concept. By "comparison," a student determines the relationship between two different scientific concepts by juxtaposed analysis. "Supposition" is the recognition of situations or conditions related to the concept. "Extension," one of the clarification functions, further illustrates the concept property by the use of atypical examples, whereas the "contrast" function defines the property of the concept through inappropriate examples.

It is not enough, for 4th grade students, to present an example of the explanation function to understand an abstract concept such as the change of a liquid to an invisible gas. Examples of the reinforcement and clarification functions must also be presented in order to correctly formulate the concepts of evaporation and boiling. Diverse examples should be presented, especially because the students' learning levels, characteristics, and previous experiences are different. Various functions and examples are presented in Table 1.

Examples of evaporation and boiling phenomena in Korean science textbooks. Traditionally, most science lessons are textbook-centered. Therefore, the examples presented in the textbooks become common explanations for students. A typical evaporation concept used in a 4th grade Korean science textbook is shown in Fig. 1.

Table 1 The functions of examples in evaporation and boiling

Function			Examples
Explanation	Empirical recognition	Students learn the properties of concepts by themselves inductively.	**Evaporation:** Drying wet laundry. **Boiling:** Water boils by heating.
	Identification	Describes the concepts by identifying the properties	**Evaporation**: Liquid changes to invisible gas because water is conserved. **Boiling**: Liquid changes to invisible gas because of the active motion of the water molecules.
	Evidence	Explain the reality of the concepts with experimental data	**Evaporation**: As time passes, the amount of water is reduced and water drops appear on the beaker wall and the wrap covering the beaker. **Boiling**: Bubbles and a cloudy vapor are observed with boiling.
Reinforcement	Application	Provide an opportunity to enhance the understanding of the concept by application.	**Evaporation**: Find surrounding examples of water evaporation. **Boiling**: Find surrounding examples of water boiling.
	Comparison	The relationship between two or more concepts is presented to confirm each conception.	**Evaporation**: Water changes into gas at the surface of the liquid. **Boiling**: Water changes into gas from within the liquid.
	Supposition	The concepts are adopted situationally or for explaining principles, theories, and processes.	**Evaporation**: If the temperature of the water is low, evaporation occurs. **Boiling**: If the temperature of the water is high, boiling occurs.
Clarification	Extension	Clarify the properties of the concepts by presenting atypical examples	**Evaporation**: During heating, evaporation also occurs at the surface of water. **Boiling**: Boiling does not always occur with an obvious source of heating. At low pressure, boiling can occur without an obvious source of heating.
	Contrast	Clarify examples and non-examples, and explain the scope of the property.	**Evaporation**: The phenomenon of drying frozen laundry is not a case of evaporation because solid ice changes to gas. **Boiling**: The phenomenon of bubbles in Sprite is not a case of boiling.

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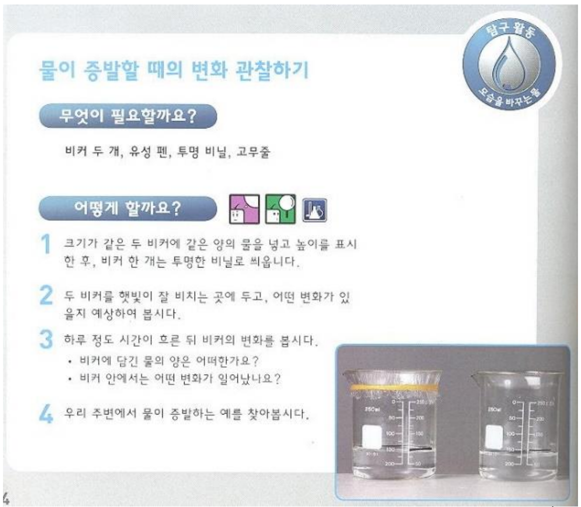

Fig. 1. Inquiry activity of "Observe the change when water evaporates" in a 4th grade science textbook

The activity and examples related to evaporation in the textbook are summarized in Table 2.

The answer to the Step 1 question presented in the 'Teachers' Guide Book' is "The height of the water in the beaker without wrap decreased and the wall of the beaker was dry. However, the height of the water in the beaker with wrap did not change and there was moisture on the wall of the beaker. The observations of the decreasing height of the water and the appearance of condensation on the wall of the beaker and surface of the wrap were proof of the evaporation of liquid water to gas as time passes." Thus, the example belongs to the evidence function, which confirms water evaporation by the students' observations.

Step 2 is classified as an application example because the students apply the concept's property to surrounding evaporation cases to reinforce conceptual understanding. The explanation in the textbook after the experiment is "We describe as evaporation the phenomenon in which a liquid changes to an invisible gas at the liquid surface. When evaporation occurs, water escapes into the air." This statement belongs to the identification sub-category of the explanation function.

The boiling concept represented in a 4th grade Korean science textbook is shown in Fig. 2.

Table 2 The functions of an example related to an evaporation activity

Title	Observation of change when evaporation occurs	
Materials	2 beakers, a permanent pen, transparent plastic wrap, rubber bands	
	Activity	Function of example
Step 1	1. Put the same amount of water in each beaker, so that the water level is the same. Cover one beaker with transparent plastic wrap and fasten with a rubber band. 2. Predict the changes in the water levels that will occur in the two beakers after time has passed in a sunny place. 3. Observe the beakers after one day. Question: How has the amount of water in the beaker changed?	Explanation: Evidence
Step 2	4. Let us look at nearby examples of water evaporation.	Reinforcement: Application
Explanation	Liquid water changes to an invisible gas by evaporation.	Explanation: Identification

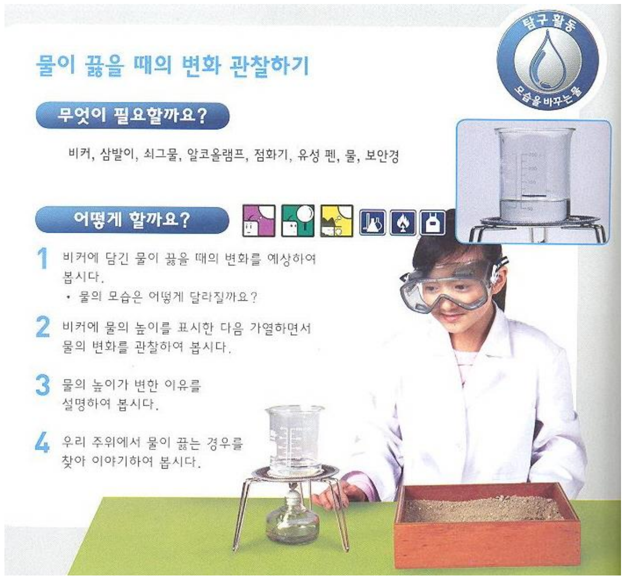

Fig. 2. Inquiry activity of "Observe the change when water boils" in a 4th grade science textbook

The activity and examples representing the boiling concept in the textbook are summarized in Table 3.

Table 3 The functions of an example related to a boiling activity

Title	Observation of change when boiling occurs	
Materials	Beaker, permanent pen, alcohol lamp, lighter, water, goggles	
	Activity	Function of example
Step 1	1. Predict the changes in the water in the beaker during boiling. Question: What is changed in the water?	Explanation: Evidence
Step 2	2. Observe the water's change while boiling after marking its height. Let us explain why the height of the water is changed. 3. Let us explain the reason for the change.	Explanation: Identification
Step 3	4. Let us look at nearby examples of water boiling.	Reinforcement: Application
Explanation	Liquid water changes to an invisible gas by boiling.	Explanation: Identification

Students are required to predict the changes in boiling water in Step 1, which is an example of the evidence function as a life experience. They are also required to explain why the height of the water decreases in Step 2, which is an identification example in which liquid water changes into a vapor. The answer to the Step 2 question in the 'Teachers' Guide Book' is "The height of the water in the beaker decreased because the water changed into a vapor and escaped into the air." This explanation furthers the students' confusion between evaporation and boiling because the same properties were invoked. Step 3 belongs to the application examples because students apply the concept property to surrounding boiling cases to reinforce their conceptual understanding.
The explanation in the textbook after the experiment is "We describe as boiling the phenomenon in which a liquid changes to an invisible gas. The reason for the decreasing height of the water is that the liquid water changes into a gas and escapes into the air." These common explanations of boiling and evaporation may confuse students. The examples in the Korean science textbook belong to the explanation functions of evidence, identification, and application. However, it is difficult to find examples that belong to the reinforcement function (comparison or supposition) or the clarification function (extension or contrast).

Method

Sample. 4th, 5th, and 6th grade students' understandings of evaporation and boiling were surveyed by questionnaire. The questionnaire was composed of four items that classified evaporation or boiling:

What phenomenon is occurring when you:

1) Heat the water and observe bubbles?
2) Don't heat the water and observe bubbles?
3) Heat the water and don't observe bubbles?
4) Don't heat the water and don't observe bubbles?

As the phenomenon, choose either evaporation or boiling. Explain your answer.

Comparing the four cases belongs to the extension subcategory of the clarification function. The hypothesis of this research is that if students had not experienced the clarification examples, they would have difficulty distinguishing between boiling and evaporation because all the textbooks present boiling in combination with an obvious source of heat and evaporation as occurring without a visible heat source. The questionnaire was reviewed and revised by a science educator and 5 science teachers who had master courses in science education. The subjects were 41 4th graders, 55 5th graders, and 28 6th graders in several schools located in a large metropolitan area. The academic level of these Korean students was average. All tests were performed in compliance with the National Bioethics Committee law of Korea and Korean National University of Education guidelines, and also state the schools' committees that have approved the research..

Intervention. After analyzing the characteristics of the students' understanding of evaporation and boiling, sixteen 4th grade students were selected from among the test group and exposed to a clarification function example. In the example, a beaker containing 70 mL water at 70–80°C was put in a vacuum vessel and the pressure was reduced by a pump. Then, the students observed bubbles in the beaker. This is an extension example of the clarification function, in which water can boil without a visible source of heat. The demonstration of boiling at lower pressure is an example of a discrepant event (Liaw *et al*. 2014; Costu *et al*. 2007).

Figure 3. The phenomenon of water boiling in an evacuated container

When students observed the phenomenon, they offered the following responses.

Student A: "Wow, it boils."
Student B: "Where, where? I want to see it. Wow, it really boils!"
Student C: "It is seriously amazing! Why does it boil without heating?
Researcher: "It boils?"
Students: "Yes!"
Researcher: "Why do you think it boils?"
Student A: "It boils! The bubbles come up in the water."
Student D: (Pointing at bubbles) "Here! These are bubbles!"

From this activity, it is found that students deduced boiling by identifying the bubbles in the water. This was their first experience of boiling without an obvious source of heat, and they accepted the situation as a clarification example of boiling. Another example presented to the students was the phenomenon of boiling water for noodles; the water was heated but not boiling. This was a contrast example of heating and evaporation.

Researcher: "Have you ever boiled water to cook noodles?" Students: "Yes!"
Researcher: "How do you boil water?"
Student B: "Hmm. First of all, I pour water in a pot and put it on the stove."
Researcher: "And then?"
Student D: "I wait till the water boils."
Student B: "After the water boils, put the noodles in the hot water."
Student A: "Put an egg, too."
Researcher: "You wait until the water boils on the stove?"
Student D: "Because the water does not boil as soon as we put it on the stove, we must wait until it boils."
Researcher: "How do you know when the water boils?"
Student C: "The bubbles appear!"
Researcher: "What do the bubbles mean? What are they?"
Student C: "When bubbles appear in the water, it means it is boiling."

After the activities, the students were given the questionnaire and interviewed to identify changes in their conceptions. The time allowed for the questionnaire was 40 min, but there was no strict limit on the time for students' thoughts. The types of answers were classified based on the reasoning behind the answers, and their frequency. The classifications were checked by the researcher and the 5 science teachers to ensure the reliability of the analysis. After the questionnaire data analysis, to clearly identify the students' reasoning, semi-structured interviews of the sixteen 4th grade students based on their responses to the questionnaire were conducted individually by the researcher. The participants had offered informed consent for the research.

Results

Students' preconceptions of evaporation and boiling under heating and non-heating conditions. The answers were analyzed from the questionnaire by the 41 4th graders, 55 5th graders, and 28 6th graders to check the consistency of their conceptions. As shown in Table 4, regardless of grade, most students thought of evaporation and boiling phenomena with an obvious source of heat as boiling. However, without a visible source of heat, the percentage of students who thought of the two phenomena as evaporation was high.

Under heating conditions, 86% of the 4th graders, 54% of the 5th graders, and 68% of the 6th graders thought of evaporation phenomena as boiling, whereas, without a visible source of heat, 72% of the 4th graders, 55% of the 5th graders, and 71% of the 6th graders thought of boiling phenomena as evaporation. The percentage of the misconceptions did not decrease according to grade.

In contrast, for the case of evaporation phenomena without a visible source of heat, the percentages of students with scientific conceptions were 100% of the 4th graders, 70% of the 5th graders, and 68% of the 6th graders. In the case of boiling phenomena with an obvious source of heat, the percentages were 98% of the 4th graders, 69% of the 5th graders, and 82% of the 6th graders. Because these two examples are traditionally presented in the 4th grade science textbook, the highest percentages of scientific conception are observed among the younger students.

Table 4. Student responses in distinguishing evaporation and boiling under heating and non-heating conditions

Situation		Response	Grade 4	Grade 5	Grade 6
Evaporation	Heating	Evaporation*	3(7)	25(46)	9(32)
		Boiling	**37(86)**	**30(54)**	**19(68)**
		No response	1(2)	0(0)	0(0)
		Total	41(100)	55(100)	28(100)
	Non-heating	Evaporation*	**41(100)**	**38(70)**	**19(68)**
		Boiling	0(0)	17(30)	9(32)
		Total	41(100)	55(100)	28(100)
Boiling	Heating	Evaporation	1(2)	15(27)	5(18)
		Boiling*	**40(98)**	**38(69)**	**23(82)**
		No response	0(0)	2(4)	0(0)
		Total	41(100)	55(100)	28(100)
	Non-heating	Evaporation	**30(72)**	**30(55)**	**20(71)**
		Boiling*	11(28)	25(45)	8(29)
		Total	41(100)	55(100)	28(100)

*Scientific conception

The numbers in parentheses are percentages

With respect to evaporation phenomena under heating conditions, the percentages of students holding scientific conceptions were 7% of the 4th graders, 46% of the 5th graders, and 32% of the 6th graders. The percentage of 4th graders was lowest. With respect to boiling phenomena without an obvious source of heat, the percentages holding scientific conceptions were 28% of the 4th graders, 45% of the 5th graders, and 29% of the 6th graders. The reason for these low percentages is that the examples for such cases were not represented in the science textbooks. Therefore, when presenting scientific concepts to students, representations of various examples that consider functional aspects are very important.

In particular, there is no example of the evaporation phenomenon in which energy is furnished by a visible heating source in the science textbooks; thus, it might be difficult to realize that energy is needed when a liquid changes into a gas. To solve this problem, evaporation phenomena that occur with obvious sources of energy should be represented to the students

The questionnaire answers and interviews were analyzed to determine the reasoning behind the classifications of evaporation and boiling.

The evaporation and boiling examples in the 4th grade science textbook are based on the identification sub-function, *i.e.,* "water changes into invisible gas." However, the examples do not efficiently help to classify evaporation and boiling for the students. The reason why the identification of evaporation is same as that of boiling could be inferred. One of the evaporation examples in the textbook is "Predict the change in the water in the two beakers after time has passed in a sunny place," an example of the evidence function. Thirteen students among 41 of the 4th graders answered, "Sunshine causes evaporation," but there were few answers by the 5th and 6th graders. The example answer from this category is "Water evaporates when sunlight is introduced, but the plastic wrap prevents total evaporation." This highlights the teaching effects of examples.

The main criterion for the classification between evaporation and boiling is heating. Of the 4th, 5th, and 6th graders, 34 (83%), 27 (49%), and 14 (50%), respectively, classified the evaporation phenomenon as boiling because of heating; examples of the reasoning behind this categorization include "When I apply heat to water for cooking, it boils," and "Because the alcohol lamp was there."

Although there are various reasons for judging evaporation phenomena, the absence of a visible heat source is the major reason: for example, "There is no alcohol lamp;" "There is no fire;" and "Because we let the water stand."

For the boiling phenomenon representation, 22 (53%) of the 4th graders, 12 (22%) of the 5th graders, and 6 (21%) of the 6th graders judged the example as evaporation because of the non-heating conditions. An example of this categorization is "If we apply heat to the water, it boils. If we don't apply heat to the water, it does not boil." Therefore, the example of boiling for the evidence function traditionally includes heating, and it confuses the students' conceptions of evaporation and boiling. Importantly, this confusion affects younger students more than older students. Eighteen students among the 41 4th graders had misconceptions about boiling based on non-heating conditions; even though they observed bubbles in the water, they did not consider the phenomenon to be boiling. They confidently asserted, "It is evaporation because there is no fire."

However, for 22 students among the 55 5th graders and 6 students among the 28 6th graders, "bubble appearance" as a comparison example was an important criterion for judging boiling phenomena. "It boils because bubbles are in the water," they said. Even though there was no visible source of heat, they thought that the water was hot because of the bubbles.

These results indicate that we need to change the boiling examples that only include heating conditions in the textbooks to expand the common scientific conceptions of 4th grade students.

The teaching effect of examples related to the clarification function. In Table 5, the analysis of the sixteen 4th grade students' responses were presented from the questionnaires and interviews after representing contrast examples in science class.

Table 5. Changes in student responses after teaching contrast examples in science class

Situation		Response	Reason	Before	After
Evaporation	Heating	Evaporation*	Water changes into gas.	2(13)	2(13)
			No bubbles	1(6)	5(31)
			Other	0(0)	1(6)
		Boiling	Heating	12(75)	7(44)
			Other	1(6)	0(0)
		Other		0(0)	1(6)
		Total		16(100)	16(100)
	No heating	Evaporation*	Water changes into gas.	3(19)	2(13)
			No bubbles	1(6)	8(50)
			No heating	12(75)	4(25)
			Other	0(0)	2(12)
		Total		16(100)	16(100)
Boiling	Heating	Boiling*	Bubble appearance	4(25)	15(94)
			Heating	12(75)	1(6)
		Total		16(100)	16(100)
	No heating	Evaporation	No heating	10(62)	1(6)
			Other	2(13)	0(0)
		Boiling*	Bubble appearance	4(25)	14(88)
		Other		0(0)	1(6)
		Total		16(100)	16(100)

*Scientific conception

The numbers in parentheses are percentages

The extension example strongly changed the students' perceptions in the cases of evaporation phenomena. Before experiencing the example, the percentage of misconception because of heating was 75%; however, this was reduced to 44% afterwards. At the same time, the percentage holding scientific conceptions based on the lack of bubbles increased to 31%.

Researcher: "At first, you thought that if you heated the water but there were no bubbles, that was boiling. Why do you change your thinking now?"

Student I: "Because, there are no bubbles."

Researcher: "But before, you thought this was a boiling example, even though there were no bubbles."

Student I: "When I cooked, I could eat noodles after the water boiled by applying heat to the water."

Researcher: "Then, you thought the bubbles would come out later?"

Student I: "Yes."

Researcher: "But, think about this situation: there are no bubbles in the water even though it is being heated with an alcohol lamp. Then, is there no boiling at this time?"

"Student I: "…."

Researcher: "This question is difficult for you. Hmm. Then, could evaporation occur when the water is heated with the alcohol lamp?"

Student I: "The water is decreasing…. Yes, it might occur."

Researcher: "Then, you think that evaporation could occur when the water is being heated by the alcohol lamp?"

Student I: "Yes….(she raises her hands as if a sudden realization flashed across her mind)…Even though we were heating the water, this is not a case of boiling because there are no bubbles."

This kind of student response may be categorized into the extension subcategory of the clarification function. The student who recognizes that evaporation can occur while heating the water by the use of proper examples has acquired a scientific conception

For the non-heated conditions, the percentage of students that assumed evaporation because of the absence of heating was 75%, but after experiencing the extension examples, this value was reduced to 25%, and the percentage of students with a scientific conception of evaporation based on the lack of bubbles increased from 6% to 50%. From the interviews of the students who changed their thoughts from boiling to evaporation as a scientific conception, it is found that many students were confident and asserted "There are no bubbles, so it is evaporation."

In the cases of boiling phenomena, the student responses as boiling because of heating were reduced from 12 (75%) to 6 (6%). Instead, the number of students with scientific conceptions based on the appearance of bubbles increased from 4 (25%) to 15 (94%). The number of students with misconceptions based on the lack of heating was reduced from 10 (62%) to 1 (6%); and the students with scientific conceptions based on the appearance of bubbles increased from 4 (25%) to 14 (88%).

The students' responses were analyzed from before and after exposure to the new examples to identify the educational effects.

Heating was found to be the most common reason for judging between the two phenomena, and underlies many students' misconceptions of evaporation and boiling. After experiencing the extension examples, four of twelve students who thought of the evaporation phenomenon as boiling changed their belief to evaporation based on the no-bubbles reason, and seven of the twelve who formed their scientific judgment on the basis of non-heating conditions changed their reason to the lack of bubbles.

After eliminating heating as a factor, the reasons behind the students' judgment of boiling were affected by the comparison example of the reinforcement function as the appearance of bubbles. For heating conditions, eleven of twelve students changed their reason for judging to bubble appearance; in the absence of heating, eight of ten students changed their reason to bubble appearance. However, the students who judged boiling phenomena based on the appearance of bubbles before the extension examples did not change their responses after the experience.

To ensure the clear representation of concepts, many examples are needed, as asserted by Gagne (1965). These results also support that claim, but we do not only suggest that more is better: instead, we maintain that the functions of the examples are also important when we represent examples.

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Conclusions and implications for teaching

A significant number of previous research studies have shown that many people, from young students to pre-service and in-service teachers, have various misconceptions about evaporation and boiling. Many causes and solutions to these problems have been proposed; however, in this study, it is suggested that the traditional examples used to enhance student understanding have instead caused misconceptions because of their limited scope. To explain abstract scientific concepts, concrete examples are generally presented, but it is difficult to represent all cases, and thus, only typical cases are selected. However, these traditional solutions can contribute to the students' difficulties in learning.

To resolve this problem, it would be better to present examples that illustrate a variety of functions rather than presenting many examples that demonstrate a single function. In science textbooks in Korea, there are many examples that illustrate the three facets of the explanation function (empirical recognition, identification, and evidence), but few involve the reinforcement or clarification functions. From these biased examples, students may have difficulty understanding scientific concepts. Students were unable to recognize boiling phenomena in the absence of heating because heating was always included in the explanation of boiling and avoided in the explanation of evaporation.

When abstract scientific concepts other than evaporation and boiling are taught, it is important to consider the example functions. Although there are limits to the quantity of teaching materials, it is better to present comparative or contrasting examples that are related to the relationship between two or more concepts, than to present each concept independently with explanation function-based examples.

According to Price & Brooks (2012), the lecture demonstrations provided by teachers in class stimulate students' performance on practice assignments, laboratory investigations, and exams, as well as enhance students' understanding of concepts. However, not all of the demonstrations that teachers present in class have proven educational effects. The important thing is not the demonstration itself, but rather, whether the demonstration is what the students need. That is, the type of demonstration is more important. Lewthwaite (2014) studied how teachers think about practical work, especially what they feature in their chemistry teaching to support student learning. In the study, many teachers (21 responses) believed that the teacher's ability to promote the learning of chemistry was important, and that the teacher can direct a student's attention to the critical aspects central to the demonstration. Therefore, it is important that teachers present essential demonstrations that solve students' difficulties in learning science concepts.

The causes of students' learning difficulties may be simpler than we think. As asserted in previous studies, evaporation and boiling are abstract concepts that include invisible gas state changes, and it is difficult to introduce these concepts to students until they can think from a microscopic point of view in a formal operational stage. However, withholding the presentation of all abstract concepts to students until they reach a formal operational stage would not be a valid solution. We must teach them the scientific concepts that operate in real life.

Many previous studies have suggested that the misconceptions of younger students can persist even upon reaching adulthood; such situations might occur because there is no further educational exposure. To teach younger students, explanation-function examples based on identification or evidence have been represented traditionally. However, reinforcement- and clarification-function examples that employ reasoning by comparison or extension are increasingly needed.

Some studies have shown that presenting situations in which students feel conflict is an important role of teachers in the classroom, and this experience fosters the development of the students' scientific conceptions. Although this study may be considered a part of this larger research context, it suggests that more concrete situations should be presented among the examples used to effect student learning. Many previous investigators have suggested that microscopic molecular representations that consider the students' developmental levels are important in the formation of abstract scientific concepts. Liaw *et al*. (2014) described in detail the relationship between the changes in students' facial micro-expressions and their learning of conceptual conflict-based instruction. By this approach, high school students' conceptions were changed to macro-submicroscopic understandings.

Based on this discussion, it is likely that the serious restrictions in the representation of science concepts for 4th grade students might interfere with future learning. However, this study demonstrates that 4th graders can develop scientific conceptions by comparing and extending proper examples with macroscopic perspectives.

The understanding of scientific concepts does not occur automatically with cognitive development. Such understanding can be determined by instruction; we can teach abstract concepts to young students by designing effective teaching examples. To this end, functional examples were suggested in this study, and effective concept changes were identified. It would be interesting in a follow-up study to see how long-lasting these gains are. This is important because the presented data showed significant drop in correct understanding in 5th and 6th graders in some areas, after they had been exposed to "boiling" and "evaporation" in the 4th grade curriculum.

This study is related to previous work that was concerned with conceptual ecologies (Paik *et al*. 2004, Paik and Cho, 2005; Posner *et al*. 1982; Strike and Posner, 1992). This study is also related to context-sensitive research (Viennot, 1985; diSessa, 1988, diSessa *et al*. 2004). Most of these studies have suggested the needs of students' experience at a macroscopic level. In contrast, this study suggests the possibility of the acceptance of scientific conceptions in younger students by categorizing context as example functions. Similar to this study, some researchers (Ashkenazi & Weaver, 2007; Zimrot & Ashkenazi, 2007) have used lecture demonstrations to promote the reinforcement function. However, those studies focused on students at higher educational levels, such as those in high school or general university courses.

For the future, research into the development of demonstrations that can foster a student's scientific understanding at the macroscopic level is needed. For example, all of the examples for boiling or evaporation phenomena involved water in this study. This makes sense for young students, since they have virtually no experience with other liquids. However, as has been noted by Jasien(2013) and Kind(2004), this can be problematic for more advanced students. Therefore, it is need to develop functional examples for other liquids for them. The educational effects of demonstrations of other abstract scientific concepts such as dissolution, acid-base phenomena, heat, and temperature could be tested for elementary school students.

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