How did Elementary Teachers Handle Critical Experiments in Science Classrooms?

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ABSTRACT

Critical Experiments (CE) in science classrooms mean, tentatively, critical situations as comparable to anomalous cases in scientific revolutions where the results of science experiments in schools are unclear, differ from the theory, or students misunderstand the purpose of the experiments. The purpose of this research is to identify what CE occurred during science classes and to investigate how elementary teachers handled them. To analyze how teachers recognized and handled CE, we selected nine typical CE from the 7^{th} Korean science curriculum. 125 teachers were selected from 8 districts' elementary schools in a local city. A questionnaire with photos of the nine CE above-mentioned was distributed to these teachers. The focus in this research was the way that each teacher handled the CE. We discovered that there were three basic ways in which teachers handled CE. When CE occurred, 51% of elementary teachers explained the correct result of the experiment (what should have happened) to the students while 40.7% of the teachers repeated to get the correct results. The focuses of handling CE varied. 57 % of the teachers focused on the 'materials' while 30% of the teachers focused on the 'theory'. The other focus was 'thinking'. Only 7.6% of the teachers answered that they gave students a chance to think about the reasons why the CE happened. By analyzing our survey results, we could determine what each teacher did as a follow up to the CE and their focus and reasoning for handling the CE this way. When the CE happened in the science class, few handled the CE with the point of view about purpose of doing experiment. As a result, students could not gain educational experience from the CE. If we use CE as a new method to teach science, it will be a good subject incorporating the nature of science in science education.

Key words : critical experiment, elementary teacher, laboratory

I. INTRODUCTION

Experimentation has always been a very important educational method to improve students' scientific and rational way of thinking (Garnett *et al.*, 1995; Hofestein, 2004). There are many positive effects of using experiments in science education. Bybee (2000) said school laboratory classes are better than other methods because with this, teachers can improve both student's conceptual knowledge and procedural knowledge at the same time. Furthermore, regarding the aspects of neuroscience of learning, laboratory class is more effective than the class based on linguistics because in the laboratory class more information can be transferred with more faculties of sensation than in a class based on verbally explaining new knowledge (Kwon & Lawson, 1999).

The science curriculum reflects the importance of laboratory classes with experiments occupying over 50% of the total science class with inquiry activities such as experiments, research, debates, field trips, project researches, and so on. In addition, if we consider students'

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attitude about science, learning in a laboratory class is important. Lazarowitz & Tamir (1994) said that in a laboratory class we can improve students' interest in science and motivation to learn science. Kim and Yang (2005) presented the idea that the laboratory class is good for improving students' attention and interest in learning science. Jang & No (2005) said, after experiments in science classes, students liked science.

Although laboratories are an essential part of science education, many elementary teachers are worried about doing experiments in a science class. Further, elementary school teachers feel a great deal of difficulty when they do experiments with students (Lee *et al.*, 1997; Yoon, 2004; Park & Kim, 1996). First, elementary school teachers find it difficult to prepare an experiment in a science class with students. Teachers think that, in order to have a successful experiment in their class, they need to conduct the experiment on their own before presenting it in class. This can be a little stressful and more time consuming than preparing for other classes. Second, teachers feel stressed when they get a result that is contrary to the theory being taught in an experiment class (Yoon, 2004, 2005). The third difficulty occurs when students misunderstand the results of an experiment. Our research shows that teachers have the greatest difficulty when, while conducting an experiment in class, the experiment ends in a result that is wrong and contrary to the lesson being taught. In this circumstance, most teachers do not know how to handle this cynical situation. We tentatively call this situation a 'Critical Experiment'.

Despite general agreement that experiments in science classes are essential, there are some negative opinions about doing experiments in science classes. Especially, the rationale is that teachers do not know how to deal with an experiment that failed to achieve the intended results of the science experiments. Critical experiments would make students' activities become to be useless (Nott & Smith, 1995; Nott &Wellington, 1996). Yet, the role of teachers in this situation becomes so important (Yoon, 2004).

When a critical experiment happens in a science class, the teacher's attitude towards science as well as his or her knowledge and understanding of science affects the way that the teacher will handle the CE. That is, the teachers' reactions are affected by what they think of the nature of science in general and what they think is the purpose of conducting experiments in the classroom (Nott & Wellington, 1995). As mentioned above, the way a teacher conducts an experiment determines whether the scientific concept is achieved and affects the development of the students' scientific thinking. Hence, it is imperative that we know and understand how teachers handle CE.

Our purposes were to determine what occurs when CE occurred during science class, to investigate the manner in which teachers' tend to handle these CE and finally to construct a foundation that will allow students to do experiments based on the inquiry process without simply focusing on getting the right result to suggest what the right role of teachers when CE happen.

II. THEORETICAL UNDERPINNING

In science, critical experiment is a conclusive, definitive experiment that is able to revolutionize a new theory or end disagreement. In using the term 'Critical experiment', we refer to situations where the results of an experiment were not clear, the result was different from scientific theory, or, even though the result was correct, students misunderstood the purpose of the experiments and, thus, could not succeed. Until now, when a science experiment in class ended with unexpected results, the experiment was labeled in a variety of manners: that is 'difficulty in laboratory instruction' or 'critical incident', or 'dilemma'. Each of these phrases has a different connotation. In this study, we chose to use 'Critical experiment (hereafter CE)' since it is the term used by Nott & Wellington (1995).

Experiments have been considered as a very important method to teach both contents and inquiry processes of science because they show us scientific inquiry of knowledge by the process of science in science's own language. Students could experience the same situation that scientists experienced by doing experiments.

Nevertheless, the significance of experiments in the classroom, it has limitations. In laboratory classes, teachers show examples of scientific appearance by doing experiments but they cannot explain why the results happen. For example, we can show the students the expansion of a metal bar by heating metal in the class. However, by doing this experiment, teachers are unable to explain the 'molecular model of a material' using the expanded metal bar as an example (Wellington, 1989). Therefore, with this limitation in experiments conducted in a school classroom, the ability to achieve correct results became the most important objective for teachers.

We could change this situation and ensure that science, as taught in schools, is not only watching experiments. This realization of the limitations of conducting experiments in schools raised many questions. Students cannot understand science simply by doing experiments. We are just showing them good examples as facts. So what we do need is communication, discussion, and imagination during an experiment. This is very important. Even though an incorrect result came out during an experiment, teachers need to teach by concept, principal, reflection of whole experiment process, and the situation itself that they did not expect. In addition, in this extra step, we need to make students communicate, discuss, and imagine (Wellington, 1994).

Still, many teachers focus too much on producing a good example when performing an experiment. They want to control the instrument(s) better, control the time better, and use better instruments to achieve easily a correct result. Is an experiment 'show'? This belief in being able to prevent any deviation from the expected result is too strong and causes teachers to think that showing a good result is all the educational effort they need to generate when doing an experiment. So, for teachers a CE is not a good experiment with which to teach. Many teachers' in training courses and seminars conducted in local schools had said that 'Why did a such bad experiment included in curriculum?' They asked to change difficult experiments in order to get clear data because those experiments are too difficult to teach for them. The experiment would be merely a 'show' for teachers and students (Kwon & Nam, 2007).

III. METHODOLOGY

1. Typical Critical Experiment

To analyze how the teachers recognized and handled the typical CE, we analyzed the 7th Korean science curriculum and extracted the contents of the experiments. Of all in the current 7th Korean science curriculum, 71.7% units required to perform experiments (from the 3rd grade to the 6th grade).

These were very high frequency of experiment classes was due to the facts elementary students are in a concrete operational period. In this period, students like to perform activities related to nature and experiments with an interesting appearance. In contrast, in the case of the 6th grade science class, the frequency of experiments conducted is slightly less than the lower grades. Upper grades' students required to incorporates

Table 1. The experiment classes in the 7th Korean Science Curriculum

Grade level	Domain				Total
	Energy	Material	Life	Earth	
3	(24/27) 88.8%	(19/23) 82.6%	(19/23) 82.6%	(18/24) 75.0%	82.3%
4	(24/27) 88.8%	(23/24) 95.8%	(9/22) 40.9%	(11/17) 64.7%	72.5%
5	(20/26) 76.9%	(13/19) 90.4%	(13/19) 68.4%	(12/24) 50.0%	71.4%
6	(21/23) 91.3%	(20/23) 86.9%	(4/28) 14.2%	(11/22) 50.0%	60.6%
Total	86.4	89.0	48.9	59.9	71.7

more discussion activities and investigation skills because these students are at the beginning of the formal operational period. The 6th grade curriculum focuses more on development of inquiry skills for concept learning, communication, and the ability to do problem solving.

By reviewing these experiments and initially interviewing 25 elementary school teachers and professors of science education, we selected representative CE. In this process, we chose 15 CE. Later, another 20 teachers surveyed these 15 CE and selected 10 of the 15 incidents as examples of what had happened to them while conducting a science class.

We then conducted another survey using the 10 CE selected. We asked another 125 elementary school teachers if they had any of the same experiences, same types of CE, when trying to conduct experiments in their classrooms.

The teachers consisted of 125 elementary school teachers from 8 different schools located in a local city. Their teaching careers were various, in details, less than 4 years' (35 persons), from 4 to 10 years' (45), from 10 to 20 years (25), and over 20 years (17 persons). Sixty-six (66) teachers had taught in the 3rd grade, 60 in the 4th grade, 62 in the 5th grade, and 64 in the 6th grade. Half of the total teachers had personally taught a science experimental class in each of the grades 3 to 6. Regarding gender, 110 teachers were female and 15 teachers were male.

We then placed the teachers' experiences with the 10 CE into 3 categories to determine the typical CE. First were the teachers who experienced these CE directly. Second were the teachers who experienced CE indirectly. Third were the teachers who did not experience any of these CE. Even though some teachers did not experience any CE themselves, they knew of colleagues who had complained about CE. We collected and placed this anecdotal evidence into the indirect experience category.

We counted how many teachers experienced each CE directly, indirectly or not at all. If the total number of those experiencing each CE was over 50%, it became a typical CE. In this third survey, 9 incidents were selected by this group of teachers.

2. Reactions to Each of the Critical Experiment

The second purpose of this study was to determine how the teachers reacted to each CE. Hence, when we conducted the above mentioned survey of experiencing 10 CE with 125 elementary school teachers, we also asked them to write about how they handled this difficult situation. It was a simple, free-style questionnaire, complete with photos of the 10 CE, given to those teachers. Among 10 CE, 1 case was not a typical CE. Therefore, we collected the data with only the 9 typical CE in this step.

With this survey, we analyzed the data by focusing on two points. The first point focused on what they did in that situation. The second point addressed the teachers' focus on the ways in which they handled the CE.

We needed a classification schemes to figure out the teachers' tendencies when handling CE because the test used in this research was a free style questionnaire. In this research, we basically used the classification schemes that used by Nott & Wellington (1995), changed this to match the information gathered from the Korean teachers. In the preceding research, Nott & Wellington used three categories such as 'the teachers' opinions', 'changing the experimental instrument(s) or material(s)', and 'manipulation of experiment data'. But there were no teachers listed in the third category. Instead, there were teachers who just ignored that faulty result. Thus, instead of our initial third category we renamed the third category as 'ignoring'. If the teachers ignored the wrong data and went on to the next lesson or admitted that they got a wrong data but moved on to the next section without thinking about the CE we placed them in the ignoring category.

We remained with a three category classification schemes but renamed them from the original schemes (Nott & Wellington, 1995) in to 'Explain the result', 'Repeat Experiment', and 'Ignoring.' to clearly identify each teacher's intentions and actions.

Within these three categories, we made subcategories to figure out each type of teachers' reaction more particularly. The subcategories sorted the teachers' focus based upon each teacher's way of handling CE. These categories are 'Student', 'Material', 'Theory', and 'Thinking'. Subcategory 'Students' incorporates those cases in which the teacher responded by thinking that the students had not dealt with the experiment instrument(s) or material(s) properly or in the correct order. Subcategory 'Material' incorporates those cases in which the teacher handled the CE by changing the instrument(s), material(s), experiment environment, and/or experiment time. Subcategory 'Theory' incorporates those cases in which the teacher reacted by explaining the theory, principle, and an example of how the theory applies to everyday life. In addition, cases in which the teacher demonstrated the correct outcome from another group in the classroom to explain the erroneous outcome in the CE of another group were included in this category. Our last subcategory 'thinking' includes cases where the teachers asked the students to think about the reason(s) why the experiment became a CE. In this category, teachers gave the students a chance to become an active learner instead of a passive learner. Most of the teachers sampled fell into one category but a few teachers were included into two categories or no category based upon their responses to the free-style questionnaire survey. Therefore, the number of teachers who responded to each CE was different than the initial 125. We analyzed the answers of this survey four times to ensure an objective result.

Ⅳ. TYPES OF CE

1. Types of CE and Teachers' Experiences

As Table 3 below shows, less than 50% of the teachers experienced CE Number 8, 'the air lacking dignity'. Hence, over 50%, or the majority, of the teachers experienced CE 1-7, 9 and 10. These nine CE were extracted and labeled as Typical CE.

Ⅴ. HOW TEACHERS HANDLE CE

We researched teachers' general tendency in handling CE. In this process, we used the Nott and Wellington's classification scheme that was used in their research (Nott & Wellington, 1995). Table 4 shows how teachers react when a CE happens.

When the CE happened, almost 92% of the teachers either explained the result that should have occurred (51.0%) or repeated the experiment so that the students could perceive the correct result (40.7%). These teachers chose an active response to deal with the CE. Only 8.3% of the teachers chose a less active response. They ignored the false result and moved on to the next lesson or simply stated that this was a wrong result without giving any explanation. These teachers took a very passive position. Meanwhile, the majority of the teachers had a strong tendency to explain the right result that should have happened or to do the experiment again instead of just going onto the next lesson. Their reason for doing so was that most teachers want

Table 2. Classification schemes to handle CE

Ways to handle	Focus of handling reaction			
	Students	Materials	Theory	Thinking
Explain the result	Students' inattention to experiment	Instrument, material, time, environment	Theories relating with experiment	Thinking about reasons why the CE occurred
Repeat experiment	Correction of students' performance	Changing the instrument(s) & material(s). Changing the experiment time and environment	Theories relating with experiment	Thinking about reasons why the CE occurred
Ignoring	Another reaction that is not included in the categories above (go on to the next lesson; ignore the wrong result, moving on to the next section without thinking about the CE, etc.)			

Table 3. Frequency of Experiencing CE

Critical experiments	Categories (%)			Frequency of experience (Direct+indirect/ direct+indirect+none)
	Direct experienced	Indirect experienced	None experienced	
1. Cloudy salt water	22.4	50.4	27.2	72.8
2. Failure of metals to expand	35.2	30.4	34.4	65.6
3. Distinguishing between vapor and steam	32.0	36.0	32.0	68.0
4. Dissolving oil ink in water	26.8	24.8	38.4	61.6
5. Determining air streams (smoke in chimneys)	36.0	21.6	42.4	57.6
6. Interaction of iodine on leaves	28.8	28.0	43.2	56.8
7. Variation of brightness among light bulbs in a series circuit	30.4	35.2	34.4	65.6
8. The air lacking dignity	15.2	22.4	62.4	37.6
9. Failure of an electric current to affect a compass	33.6	23.2	43.2	56.8
10. Displacement of water with different weights	28.8	23.2	48.0	52.0
Average	29.92	29.52	40.56	59.4

Table 4. General tendency of how CE are handled

	Categories of the different ways to handle CE		
	Explain the result	Repeat experiment	Ignoring
Percentage of teachers included in category	51.0%	40.7%	8.3%

students, when doing an experiment, to discover scientific knowledge and to obtain declarative knowledge (Yoon, 2004; Yang *et al.*, 2006a).

The teachers had a strong tendency to explain the right result that they had expected. This tendency appeared most often when the teachers did not have enough class time and when the science class focused on learning a scientific concept or principle. When teachers understand and know the correct result of an experiment it decreases a teacher's uneasiness and enables them to handle a CE well.

As we know from previous research about the nature of science and the purpose of science education, many teachers thought declarative knowledge of science is reasonable and valuable for science education. These reasons are so strong in the minds of teachers that we think there are many teachers who want to explain the right result they expected when a CE happen.

It seems that the teachers who handled the CE by doing the experiment again kept in mind the nature of science that states that it is important to evaluate experiments repeatedly. We think that most of the teachers handle CE by doing the experiment again because they knew what materials, instruments, and environment to change. They knew this probably because they were influenced by their university education and their teachers' training courses regarding science experiments. However, there are some teachers' training courses of science that focuses too much on not making a CE.

1. The Tendency to Handle the CE by Domain

Table 5 shows us how teachers' tend to handle the CE by domain of science subject.

In the case of 'energy' and 'life' domains, the teachers of these two parts who explained the result and did the experiment again were almost 45%. Teachers who did the experiment again were a little higher than the teachers who explained the result by 3~4%. How-

Table 5. Tendency of the way to handle CE by domain

Domain	Number of teachers who answered in each category (%)			Sum
	Explain the result	Repeat experiment	Ignoring	
Energy	129 (43.1%)	139 (46.5%)	31 (10.4%)	299
Material	257 (61.5%)	130 (31.1%)	31 (7.4%)	418
Life	45 (45.4%)	49 (49.5%)	5 (5.1%)	99
Earth	31 (34.4%)	51 (56.7%)	8 (8.9%)	50

Table 6. General tendency and focus of the teachers after CE

Domain	Focus of teachers while handling CE (%)			
	Student	Material	Theory	Thinking
Energy	21 (7.8%)	157 (58.6%)	60 (22.4%)	30 (11.2%)
Material	13 (3.4%)	203 (52.5%)	164 (42.4%)	7 (1.8%)
Life	18 (19.1%)	52 (55.3%)	15 (16.0%)	9 (9.6%)
Earth	3 (3.7%)	62 (75.6%)	11 (13.4%)	6 (7.3%)
Total	55 (6.6%)	474 (57.0%)	250 (30.1%)	52 (6.3%)

ever, in case of the 'material' domain, the teachers who explained the result were 61.5%. This is 30% higher than the number of teachers who did the experiment again. The teachers who repeated the experiment were 31.1%. It appears that, in the case of the 'material' domain, the reason more teachers explained the result was because there are many experiments dealing with concepts such as vapor, steam, and solutions. Another reason may be that it is easier to explain what the result should have been than to achieve a correct outcome by redoing the experiment. Further, even if teachers could achieve a correct outcome, they thought it would be more beneficial to explain just the principal. This is because, even if they are able to produce a correct outcome by redoing the experiment, they will still have to explain the principal anyway. So, in order to save time and effort, some teachers prefer to circumvent redoing the experiment and simply explain the concept. On the contrary, in the case of the domain 'earth', the teachers who did experiment again were 20% higher than the teachers who merely explained the result.

2. Frequency of the Focus on the Way Teachers' Handled the CE

In this research, we examined the focuses and tendencies of the teachers when confronted with a CE. We studied the characteristics of the teachers and the manner in which they handled this situation. This process provided us with information about the teachers' behavior that is more practical.

Table 6 shows what the teachers were focusing on while they were handling CE.

Fifty-seven percent (57%) of the teachers' focus was on materials such as instruments and the environment of the experiment. This result was similar to a previous research in 1996 (Park & Kim, 1996). In the previous research, they suggested that many materials and instruments were a big influence on the result of an experiment. Hence, teachers need to take care when selecting and using materials and instruments. For example, in the case of the domain 'energy', there are effects caused by the physical characteristics of the instruments used in an experiment.

In the case of the 'material', there are effects caused by a reagent; materials; quantitative and qualitative expressions. Raising, growing, collecting, using, and buying materials that are easily available affect the domain 'life'. In the case of the domain 'earth', there are effects caused by combinations of materials, instruments, ways, and environment. Accordingly, in this research, we thought teachers knew already the importance of the preparation of materials and instruments for an experiment class. However, they did not have enough time to do so because elementary school teachers need to prepare for several subjects at the same. This is why we think they could not prevent a CE from happening in their classroom.

30.1% of the teachers focused on 'theory', which includes experiments, principals, and examples of everyday life.

Only 6.3% of the teachers gave a chance to students to think about why the CE occurred. It was very few numbers compared to other categories. By doing an experiment in the science class, a student can achieve knowledge of science but more importantly, they can experience the inquiry process, scientific creativity, and the nature of science. For this reason, we must give students chances to analyze and solve the puzzle of CE. Yet, even nowadays, many teachers maintain a classical viewpoint about the nature of science, do not have enough time to organize and prepare for a valuable process, and/or do not have enough space where they can do an experiment conveniently.

According to previous research, the problems that teachers experienced while conducting an experiment varied by domain (Park & Kim, 1996). If that is the case, teacher's handling of CE is different by domain (see Table 6).

In all domains, over 50% of the teachers focused on material. Especially in the case of the Earth domain, 75.6% of the teachers focused on material. In the case of the domain 'material', 42.4% of the teachers focused on the category 'theory' that incorporates theory, principal, and examples of everyday life. 19.1% of the teachers focused on students in the 'life' domain. This was a little higher than the other domains.

3. Frequency of the Focus on the Way Teachers' Handled the CE by Career

Table 7 shows what the teachers were focusing on and how they handled CE based upon the amount of teaching experience that each teachers had. If we analyze the data over all, the teachers with under 4 years' experience had the highest tendency of doing the experiment again with a focus on the experiment's material, which includes the instruments and the environment.

Also, the teachers who had 4 to 10 years experience had the same strong tendency of doing the experiment again and focusing on 'material'; but, the percentage of teachers dropped slightly. Contrary to this, the percentage of teachers who chose to explain the result expected based on theory increased a modestly compared to teachers with under the 4 years experience. In the case of teachers with a 10 to 20 year career, the frequency of explaining the result using theory was higher than the others. In the case of teachers with over 20 years experience, the percentage of teacher who redid the experiment with a focus on material was higher than the others.

In the case of teachers with less than 4 years experience, the percentage of teachers who gave students a chance to think about why the CE happened (Thinking) was 4.4%. These students, then, were given a chance to be the person to solve the problem. Unfortunately, few teachers (4.4%) utilized this teaching process. The number of teachers with 4 to 10 years experience was 6.1% and teachers with 10 to 20 years experience was 8.2%. Further, teachers with over 20 years experience was 4.7%. For those teachers with less than 20 years experience, the more experience a teacher had the greater likelihood that the teacher would use 'Thinking' as a way to handle a CE. However, in case of

Table 7. Frequency of the focus on the way teachers' handled the CE by Career

Methods / Career	Explain the result				Do the experiment again				Ignoring
	Student	Material	Theory	Thinking	Student	Material	Theory	Thinking	
Under 4	9 (3.5%)	33 (12.9%)	61 (23.9%)	6 (2.4%)	9 (3.5%)	112 (43.9%)	1 (0.4%)	5 (2.0%)	19 (4.5%)
From 4 to 10	9 (2.5%)	46 (12.7%)	104 (28.7%)	13 (3.6%)	4 (1.1%)	138 (38.1%)	2 (0.6%)	9 (2.5%)	37 (10.2%)
From 10 to 20	8 (5.0%)	38 (23.8%)	47 (29.4%)	10 (6.3%)	4 (2.5%)	38 (23.8%)	0 (0.0%)	3 (1.9%)	12 (7.5%)
Over 20	10 (7.8%)	28 (21.7%)	34 (26.4%)	6 (4.7%)	2 (1.6%)	41 (31.8%)	1 (0.8%)	0 (0.0%)	7 (5.4%)

the teachers with a 20-year or more careers, the frequency decreased.

VI. THE TYPE OF WAYS TO HANDLE EACH TYPICAL CE

In this section, we checked the teachers' point of view when handling each Typical CE.

1. The 1st CE: Cloudy Salt Water

This CE is related with Unit 4 of the 3rd grade level, 2nd semester. In this unit, students dissolve many kinds of powder. They need to determine which powders can be dissolved or mixed. During the experiment, students observe the solution. In this process, the degree of clearness is the standard of checking the mixture or solution. Usually when students dissolve salt in water, the color of salt water is clear. Other times, the salt water's color is grey. Hence, some students write that the result of their experiment is that the salt water's color is grey. Thus, the students are confused as to whether it is a mixture or a solution. With this CE, Table 8 shows the teachers' focus and how they handled this situation.

When this CE happened, 64.5% of the teachers thought the salt was the origin of the problem. Their focus was material. Of these, 33.1% of the teachers explained the result and 31.4% of the teachers did the experiment again. In this CE, it is highly likely that salt was the main factor that caused the strange effect to take place. If so, it is highly likely that teachers would focus on 'material'. Hence, if the teachers are more careful with the material used (salt) they can prevent the CE from happening.

2. The 2nd CE: Failure of Metals to Expand

This CE is in Unit 5 of the 4th grade level, 2nd semester. By using heat, students check whether a copper wire is easier to expand in length, making it longer than an iron wire. As easy as this may sound, it is sometimes hard for the students accurately heat the two wires to the point where they can distinguish the difference in the heating properties of the two metals. Sometimes the wires remain the same length.

As we examined the general tendencies of the teachers above, most of the teachers focused on the category 'material'. Of those that chose to redo the experiment, 59% of these teachers singled out 'material' as the cause for the experiment failing. They said they changed the kind of copper line used or made the heating time longer.

This CE, above all others, is an excellent learning tool for teachers and students. While teaching and conducting this experiment, teachers do not have worry about the result. Any result is educational and beneficial to the students. This experiment is an excellent opportunity for students to be creative and think about the reason for the CE happening. Students can set up a better experimental instrument by themselves. This

Table 8. The focus and methods of the teachers handling the 1st CE

Methods / Focus	Explain the result				Repeat experiment				Ignoring
	Student	Material	Theory	Thinking	Student	Material	Theory	Thinking	
No. of teachers (%)	6 (5.1%)	39 (33.1%)	17 (14.4%)	3 (2.5%)	2 (1.7%)	37 (31.4%)	0 (0%)	1 (0.8%)	13 (11.0%)

Table 9. The focus and methods of the teachers handling the 2nd CE

Methods / Point	Explain of result				Doing experiment again				Ignoring
	Student	Material	Theory	Thinking	Student	Material	Theory	Thinking	
No. of teachers (%)	3 (3.0%)	16 (16.0%)	18 (18.0%)	1 (1%)	0 (0%)	59 (59.0%)	0 (0%)	0 (0.8%)	3 (3.0%)

provides an invaluable experience to both teachers and students.

3. The 3rd CE: Distinguishing between Vapor and Steam

This CE is in Unit 7 of the 4th grade level, 2nd semester. In this experiment, students need to create vapor by boiling water. They put a small glass tube near the Erlenmeyer flask that contains boiling water. The students monitor the process checking for vapor to occur. They do this by observing the small water drops that appear on the glass tube. The major hurdle here is that before we even put the glass tube near the open hole of the Erlenmeyer flask, there is steam emitting from the flask. The students see the steam and erroneously think it is the vapor. However, they need to learn that steam is liquid and different from vapor.

In Chemistry, usually many teachers focused on 'material'. But, in this Chemistry experiment, 78.9% of the teachers focused on 'theory'. Even though students observed water drops appearing on the glass tube, in many cases these drops were caused by steam. This CE happened because students confused the concepts of vapor and steam.

It seems that many teachers explained the concept of vapor and steam based on theories to help the students construct the right concept, even though many teachers themselves did not know the difference between vapor and steam.

4. The 4th CE: Dissolving Oil Ink in Water

This CE is in Unit 2 of the 5th grade level, 1st semester. In this experiment, students learn which solvents can dissolve which solutes. Solvents can be dissolved if the solute is the correct one. Elementary students use an oil pen and a water pen as different solutes with acetone and water as different solvents. They open each pen and take out the center tube cutting it into two small sticks. They then put one stick in water and the other stick in acetone. The oil should not dissolve in water. However, what it will do is float down through the water weaving back and forth giving an appearance similar to dissolving. The blueness of the oil shows through the water giving the illusion that the water is turning blue. Yet it is not. When students observe these they mistakenly assume that the oil has dissolved in the water.

Here 53 teachers explained the concept of dissolution or gave an example of everyday life relating to this experiment. The teachers said they explained the concept of dissolution because the student misunderstood the appearance of the oil ink going down into the water. We see that 22.9% of the teachers said students had used the wrong material. They said students originally did not understand that the oil sticks could not dissolve in the water. 16.2% of the teachers changed the ink pen and did the experiment again or did this experiment in a different way. First, they wrote something on a piece of paper with an oil pen. Next, they put the paper in water. It was very interesting.

Table 10. The focus and methods of the teachers handling the 3rd CE

Point \ Methods	Explain of result				Repeat experiment				Ignoring
	Student	Material	Theory	Thinking	Student	Material	Theory	Thinking	
No. of teachers (%)	0 (0.0%)	0 (0.0%)	75 (78.9%)	0 (0.0%)	1 (1.1%)	11 (11.6%)	1 (1.1%)	0 (0.0%)	7 (7.4%)

Table 11. The focus and methods of the teachers handling the 4th CE

Point \ Methods	Explain of result				Repeat experiment				Ignoring
	Student	Material	Theory	Thinking	Student	Material	Theory	Thinking	
No. of teachers (%)	0 (0.0%)	24 (22.9%)	53 (50.5%)	2 (1.9%)	1 (1.0%)	17 (16.2%)	0 (0.0%)	0 (0.0%)	8 (7.6%)

39.1% of these teachers we commented above said, as a matter of fact the oil pen can dissolve in the water because there are some ingredients in the oil pen that can be dissolved in water. However, the teachers did not explain this practical information to the students. With this CE, we realized that, still, many teachers think that they should only teach the right answers in the test and only explain the experiment result as presented in the textbook. So teachers thought they needed to teach without making any changes in the textbook. We think this is based on their mind of nature of science.

5. The 5th CE: Determining Air Streams (Smoke in chimneys)

This CE is in Unit 3 of the 5th grade level, 1st semester. The title of this unit is 'wind and temperature'. This experiment is about learning how wind is created and affected by temperature. This is done by using a small box whose bottom is separated into two compartments. The students will place ice in one compartment and warm sand in the other. Each compartment has its own chimney poking out of the top of the box. The students place a burning stick of incense between the two compartments. Due to the temperature difference between the two sides, smoke should come out of just one chimney, the one over the warm sand. However, sometimes, smoke came out of both chimneys.

In this lesson, a majority of the teachers repeated the experiment (56.6%). Of these, a small minority of the teachers (6.6%) focused on something other than material while 50% of the teachers did focus on materials. These teachers made the temperature gap between the two compartments larger, increased the amount of smoke, and increased the amount of the observation time when they did the experiment again. They focused on the instruments and materials used and on the amount of time.

Of those teachers that merely chose to explain the result, 18.9% focused on the materials used when explaining the result that the students should have achieved. On the other hand, 12.2% of the teachers explained the result by using an example from everyday life or theories.

6. The 6th CE: Interaction of Lodine on Leaves

This CE is in Unit 7 of the 5th grade level, 1st semester. This unit is about the appearance and the role of leaves. Especially, this experiment focused on photosynthesis of leaves. Students checked how a plant obtained nutrition by observing the reaction between iodine and starch. Students attached an aluminum tape on a part of a leaf. The next day, they put that leaf in a double boiler filled with alcohol, which they boiled. After this process, students placed the boiled leaves in a Petri dish and dropped iodine on the leaves. The part of the leaf that was not taped should have changed its color by reacting with the iodine. This is because the

Table 12. The focus and methods of the teachers handling the 5th CE

Point \ Methods	Explain of result				Repeat experiment				Ignoring
	Student	Material	Theory	Thinking	Student	Material	Theory	Thinking	
No. of teachers (%)	1 (1.1%)	17 (18.9%)	11 (12.2%)	2 (2.2%)	2 (2.2%)	45 (50.0%)	0 (0.0%)	4 (4.4%)	8 (8.9%)

Table 13. The focus and methods of the teachers handling the 6th CE

Point \ Methods	Explain of result				Repeat experiment				Ignoring
	Student	Material	Theory	Thinking	Student	Material	Theory	Thinking	
No. of teachers (%)	16 (16.2%)	10 (10.1%)	13 (13.1%)	6 (6.1%)	2 (2.0%)	42 (42.4%)	2 (2.0%)	3 (3.0%)	5 (5.1%)

starch in the leaf mixed with the iodine. The part of leaf that was taped did not change its color. Despite this, there, sometimes, is no difference between the part of the leaf that is covered by tape and the part that is not.

Here, 42.4% of teachers repeated the experiment by changing the materials of this experiment. Some teachers changed the kind of plants used, the time of treatment, the weather environment, and the materials. 16.2% of the teachers focused on the actions of the 'students'. They thought this CE happened because students did not tape the leaf well. So, they explained to students the result needed to achieve the correct outcome. This percentage of teachers focusing on students is higher than in the other typical CE. This fact shows us that students can be the main factor in the result of an experiment. We think this is very valuable situation. Even though they achieved an incorrect result, students can recognize that they have a significant impact on the result and that they are an important factor in the process of science exploration.

7. The 7th CE: Variation of Brightness among Light Bulbs in a Series Circuit

This CE is in Unit 6 of the 5th grade level, 2nd semester. This is an experiment to connect two light bulbs in various ways. This whole process is learning about electric circuits. When students connected two light bulbs in a series circuit, the brightness of the two lights bulbs should be same. Yet, sometimes one light bulb is brighter than another. When students compared the brightness of the lights bulbs in a series circuit and a parallel circuit, there was no difference in the brightness of these two kinds of circuit. Hence, students were confused.

In this lesson, 57.6% of the teachers repeated the experiment by changing the light bulbs while 16.2% of the teachers explain the correct result by referring to the light bulbs. Further, 13.1% of the teachers explain the correct result using theory and 8.1% of the teachers gave students a chance to think about the reason for the result of the CE.

8. The 8th CE: Failure of an Electric Current to Affect a Compass

This CE is in unit 7 of the 6th grade level, 1st semester. This is an experiment to demonstrate how the direction of a magnetic field can be seen by the changing direction of a compass near an electrical wire charged with an electric current. However, sometimes, even though there is a line charged with an electric current, the compass did not move or the movement was too small. Sometimes there is a case where the compass kept changed its direction. When this is the case, it is very difficult to know in what direction the compass has moved.

The greatest number of teachers (48.1%) chose to repeat the experiment and focus on the materials used. They did experiment again by changing the battery to a new one or used more batteries in the experiment.

Table 14. The focus and methods of the teachers handling the 7th CE

Methods / Point	Explain of result				Repeat experiment				Ignoring
	Student	Material	Theory	Thinking	Student	Material	Theory	Thinking	
No. of teachers (%)	0 (0.0%)	16 (16.2%)	13 (13.1%)	5 (5.1%)	0 (0.0%)	57 (57.6%)	0 (0.0%)	3 (3.0%)	5 (5.1%)

Table 15. The focus and methods of the teachers handling the 8th CE

Methods / Point	Explain of result				Repeat experiment				Ignoring
	Student	Material	Theory	Thinking	Student	Material	Theory	Thinking	
No. of teachers (%)	0 (0.0%)	13 (12.5%)	24 (23.1%)	7 (6.7%)	1 (1.0%)	50 (48.1%)	1 (1.0%)	4 (3.8%)	4 (3.8%)

On the other hand, 23.1% of the teachers explained the correct result using the right-hand rule. Another 10.5% of the teachers gave students a chance to think about the reason for the CE. This frequency is a slightly higher than in the other typical CE.

In the case of this CE, rather than the result was a failure, the movement of compass was too small. It did move as expected but it was too small to detect. So it is better for teachers to make students think about the importance and methods of observing the result of an experiment seriously and clearly. For this reason, we need to think about which one is better; making the students observe more carefully without changing any of the experiment's parameters or insuring, by changing the material(s) that the results of the experiment will be more visible to the students.

9. The 9th CE: Displacement of Water with Different Weights

This CE is in Unit 1 of the 6th grade level, 1st semester. This is an experiment in which we observe that a weight placed in water will cause the water to overflow and that amount of the overflow will tell us the size of the weight. Logically, the weight of the overflow and the weight of an object placed in the water have to be same. Unfortunately, when some students checked both weights they found that the weights were not the same. This happened frequently. Usually the weight of over flown water is a little lighter than the weight of the object in the water. This happens because, during the experiment, not all of the over flown water is captured and weighed. At times, a little bit of the over flown water remains in the tray when being poured into the beaker. It is very hard to control this factor for students because, during the whole process, students should use extreme delicate control. Regrettably, in the school laboratory class and for the student, it is almost impossible.

In this instance, 22.9% of the teachers explained the correct result based on the theory and 10.4% of the teachers explained the correct result by checking the students' performance and the materials used in the experiment. It was very interesting that 22.9% of the teachers chose to go to the next lesson by admitting that the wrong result was an observational error. This is a very different case compared to the other typical CE. We thought that, during the experiment, students could see some water drops from the over flown water that had stuck onto the tray that had caught the overflow. Hence, the students could easily understand why the result was different. If teachers knew this could happen then they can ask students to do a more deliberate observation during the experiment. Doing so will help students think about their unexpected result; a result different than explained in the textbook.

VII. CONCLUSIONS AND DISCUSSION

From the 7th Korean science curriculum, we extracted typical CE which caused elementary teachers' embarrassment. We investigated various ways in which to handle these typical CE and what their tendency was after experiencing these CE after categorization into experiences by branch and teaching careers in elementary schools.

Over 50% of the teachers had experienced a typical CE in their classroom, treated CE as material troubles in the experiment. These 'materials' troubles could include, but are not limited to, instruments, amount of time and environment. Most of us think that if we are meticulous in the use of the instruments and materials involved in an experiment that we can prevent or

Table 16. The focus and methods of the teachers handling the 9th CE

Point \ Methods	Explain of result				Repeat experiment				Ignoring
	Student	Material	Theory	Thinking	Student	Material	Theory	Thinking	
No. of teachers (%)	10 (10.4%)	10 (10.4%)	22 (22.9%)	9 (9.4%)	10 (10.4%)	11 (11.5%)	0 (0.0%)	2 (2.1%)	22 (22.9%)

minimize an erroneous result; hence preventing a CE from happening.

A CE which has either a negative or positive condition should be used to improve students' inquiry skills and thinking abilities. Conversely, if this CE creates student misconceptions, it should be eliminated and replaced with another experiment. However, the CE itself could be an inevitable product in the process of teaching science. Therefore, it would be better if a teacher admits to this situation in the science class and then, prepares to find a new method to handle CE educationally. For the most part, it is the teachers' responsibility to ensure CE to be educational. Therefore, it is imperative that we provide guidance to teachers so that they can handle CE in a positive and educational manner.

When the CE happened, only 7.6% of the teachers suggested that the students take the opportunity to consider the reason why the CE occurred. Science classes usually would be teacher-centric, i.e. the teachers are the main characters who organize the students' learning and thinking. Teachers handle CE in their own ways as if creating their own recipe. Students do not have opportunities to form their own reasons to explain the CE. In order to make the science experiment a meaningful inquiry, we have to find a way to induce both teachers and students to focus on not only the result but also on the process of the experiment (Driver *et al.*, 1996). Students can experience learning about the nature of science when they fully consider and debate about both process and result of CE (Duschl, 1990).

The nature of science and teachers' recognition of the purpose of an experiment has a big influence on the tendency of the ways that CE are handled. Therefore, to improve students' scientific inquiry skills, thinking power, and to make them have an active position in experiments, we need to suggest that teachers take a chance to change their view about the nature of science and conception about the purpose of conducting an experiment and, instead, take a modern point of view. Science teachers need to realize the importance of CE and to know how to use CE as a good opportunity to teach the nature of science to students.

1. Implications

If students are acquainted with the meaning of raw data that they collected and the process of science that they performed, it is a good chance for students to experience science as an occupation, and to consider the new inventions of science, and the moral problems caused by these inventions. A serious problem is that teachers do not consider the effect of their own behavior towards the extemporaneous handling of CE. We do not need to focus on the development of a new recipe or a new instrument to achieve a flawless result. To turn this 'mistake' into an educational event, we need only admit that the CE occurred and then, use this CE as a tool to learn scientific process.

Thus, teachers need to develop new strategies for leading students in that direction instead of ignoring CE. When CE occurs, teachers should worry about how to handle it. CE are common and are related to social factors. Hence, it is impossible to avoid inclusion of this kind of experiment in the curriculum, by either standardizing all experiment classes or setting CE into one form.

We suggest new directions on how to apply CE.

1. Students need to repeat an experiment. They will think about the reason for the occurrence of the CE together and control the factors again (Natural process of science),
2. Students need to debate the outcome of the experiment. It will be a chance to improve students' analytical skills by communication (Communication with the CE),
3. Students need to measure and verify the data repeatedly. With this process they will acquire highly sophisticated inquiry skill (Accurate operation),
4. Students need to present the result of an experiment in front of an audience: They will learn about how to share the result of the raw data together (Sharing raw data),
5. Teachers need to introduce the history of science incorporating CE. Students can experience being a scientist via scientific history. With this process, they can experience a moral situation relating to science (Experience history of science), and

6. Teachers are able to use video files. It will overcome time limitations (Introduction of movie files) (Kwon & Nam, 2007).

Until now we have suggested how to handle CE in a constructive manner. CE can be a good educational starting point to explain the meaning of a science process and the nature of science. If CE is a natural occurrence in science, teachers can think about, analyze and discuss the CE itself with students. We can think about the meaning of an experiment, what they did in the experiment class, and science itself. Further, this could be a good opportunity to allow students to truly understand the kind of real research that scientists are doing and the nature of science.

2. Further Research

This research focused on how elementary school teachers handle CE. In the class, there are two main characters, the teacher and student. Teachers and students have always collaborated to create educational activities in science classes. Hence, if we research students' thinking and reactions when the CE occurs in science classes, we can make a meaningful foundation in being able to overcome the limitation of CE in today's science education.

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